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THE INSTITUTION OF PETROLEUM TECHNOLOGISTS.

THE ONE HUNDRED AND FIFTEENTH GENERAL MEETING of the Institution of Petroleum Technologists was held at the House of the Royal Society of Arts, John Street, Adelphi, W.C., on Tuesday, December 11, 1928. The Chair was taken by Mr. Ashley Carter, Member of Council.

The Chairman, at the opening of the meeting, stated that the President had asked him to express his regret that he was unable to preside over the meeting.

The Secretary reminded the members that nominations for Council should be in his hands not later tha January 31 next.

The Secretary announced that the following gentlemen had been elected :—

Members.—Cecil Thomas Barber, Jacob Koppes, Peter Niven, Alfred William Henry Phelps.

Transference to Member.—Harry Standish Ball, Victor Dvorkovitz, Philip Noel Rogers.

Associate Members.—Cyril Arthur Burbridge, Cecil John Fielder, John Haker, David John Lewis, Gordon Anstie Richards, James Dodds Shackleton, Percy Henry Snow, Frank Redvers Tucker.

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Students.—Howard George Vivian Davies, Philip Max Falconer, Harold Walter Guess, Arthur Gilbert Leighton, John Leslie MacLeod, Ian McCallum, Maxwell John Mehler, Arthur Charles Sebastian Rawlinson, Thomas Gordon Robson, John Guy Ainsworth Roe, Patrick Archibald Spens.

Associate.—Charles Clark Mylles.

The following paper was then read :—

Madagascar and Its Oil Lands.

By ARTHUR WADE, D.Sc., A.R.C.S., F.G.S., M.Inst.M.M., F.Am.G.S. (Member).

I. INTRODUCTION.

VERY little has been written in English concerning Madagascar and little is known of the great island by English-speaking peoples. A good deal has been written in French, but the information conveyed is not always as reliable as it might be.

This paper is the result of a study of the island which extended over a considerable period and included field work throughout the whole of a dry season. Many observations are, so far as we have been able to gather, here recorded for the first time. It is the purpose of the paper to endeavour to give sufficient information to enable a future worker in this field to start out with a better knowledge of the island than we had.

Most of the French writers deal with the island in a general way, studies in more detail being concerned, for the most part, with the more settled regions round the capital and other centres of population, to a few coastal areas or to areas where some form of development, such as mining and agriculture, is in progress. Such investigations have been very ably carried out by French experts. There are, however, still parts of Madagascar which have never been or have been only partly explored, there are many facts concerning the island which have never been stated and many phenomena which have never been investigated, so that there is wide scope for future research work. It is a country full of surprises, full of the extraordinary to such an extent that there were times when we had the feeling that we were in a land which did not belong to this planet.

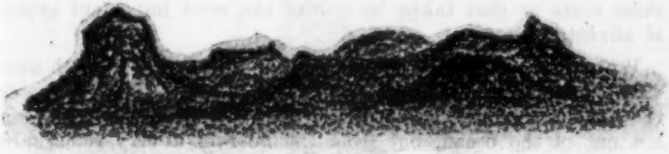
II. GENERAL PHYSICAL FEATURES.

(*a*) *The Gneissic Plateau.*—Madagascar is the third in size of the world's great islands, New Guinea and Borneo being slightly larger. It covers an area of rather less than 230,000 sq. miles. Its shape has been described as that of a human footprint. The island is 1000 miles long and about half that in breadth, the long axis running N.N.E. to S.S.W.

Looking at a map of the African Continent it is clear that Madagascar is a geographical part of that land mass. Geologically the island is an extension of the fundamental gneissic platform

of Africa. From almost every other point of view Madagascar is as un-African as it can be and is more closely allied with Indo-Asia than with Africa, as we shall see later.

The island consists, for the most part, of a great central gneissic plateau averaging over 4000 ft. in elevation above sea-level. High



GNEISSIC PLATEAU WITH WORNDOWN GRANITE DOME.

points run up to over 7000 ft. This central plateau must be, and has the appearance of one of the oldest land surfaces on the globe. There is no evidence which would suggest complete submergence at any time since the Pre-Cambrian ages. This gneissic platform forms a huge block which terminates precipitously to E. and W. Around the margins of the platform and abutting against its walls are sedimentary deposits of much later ages.

GRANITE PLUG NEAR TENOARIVE.

The gneisses approach very near to the sea to the East and the wall plunges steeply into the depths of the ocean. The coastal strip is, therefore, narrow. The rainfall is much higher and more evenly distributed throughout the year on this eastern side than it is elsewhere on the island and this has resulted in much weathering and denudation along the margin of the gneissic wall. Torrential streams have cut deep and narrow valleys and gorges back into

it and the warm and humid climate has caused these eastern slopes to be clothed with dense tropical forests which disappear as soon as the plateau is reached. Early invaders reached the interior of the island by these valleys and even to-day the one line of railway in the country, that from the port of Tamatave to the capital, Tananarive, follows one of them, taking, probably, the same route as that taken by one of the most important groups of adventurers.

When we come to the western side of the plateau a much more varied and interesting set of conditions exists. On this side, the plateau terminates in sheer cliffs of barren gneiss which rise not out of the ocean, but from the floor of a very remarkable valley which runs parallel with the edge of the plateau for the whole length of the island. The plateau does not reach the same elevations on this western side as it does on the east, but it is still 2000 to 3000 ft. above sea-level. Wide hanging valleys cut notches in the top of the plateau and gaps in the tops of the precipices. Occasionally, the wall is broken by steep boulder filled ravines or gorges. In one or two places the gneisses descend to the floor of the valley in great steps apparently due to faulting. The climate being dryer on this side of the island the rocky walls stand up, bare and sheer, above the valley below, affording little foothold for vegetation of any description. The edge of the gneissic plateau on this side is called "The Bongolava."

Although this central area of elevation consists, for a large part, of extensive plains, great ridges, consisting chiefly of granitic mountains, break its surface. Of greater interest to the geologist perhaps are areas in which stupendous domes of granite, together with bosses and knobs, weird and fantastic in shape, stick out baldly from the gneissic plains. The kaleidoscopic changes in such a landscape, the great surrounding plains which seem to be bare and empty, altogether devoid of life, and the impression of vast distances which they give, give rise to feelings of awe. There is something which is absolutely unearthly about such areas which exist on the plateau. There is some fall to the west in the plains, but there is no general slope in this direction, it is rather a matter of terracing.

(*b*) *The Triassic Valley.*—Facing the Bongolava and running almost parallel with it at a distance which varies from 2 miles to over 20 miles is another precipitous wall standing up to 1500 ft. above sea level. This is an escarpment of Jurassic grits and limestones. This escarpment does not run so persistently for the whole length of the island as does the gneissic wall. It is broken into three parts, the first gap occurring along an axis running from

GENERALISED SECTION ACROSS THE TRIASSIC VALLEY.
(DIPS AND VERTICAL SCALE EXAGGERATED.)

Cap St. André to the south-east, and the second, in the neighbourhood of Nossi-Bé near the northern end of the island. The southern part is called the Bemaraha and the central part Ikahavo Ankara. The deep and continuous trench-like depression between these precipitous valleys is known as the Triassic Valley, a misnomer, since only part of the floor of the valley is covered by Triassic sediments, and not the whole of it, as was thought when the name was given.

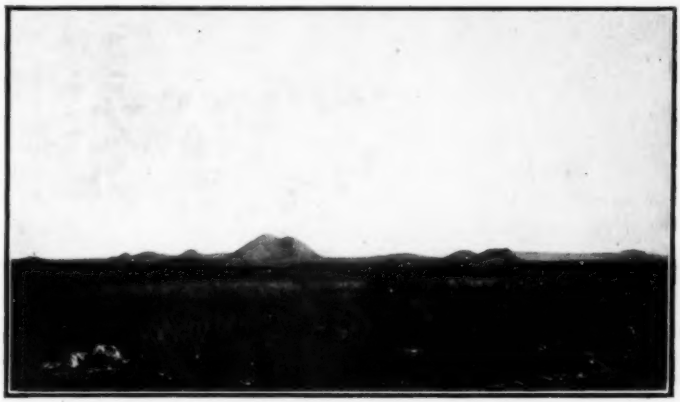
The breach in the Jurassic escarpment in the neighbourhood of Cap St. André is full of interesting things. The Triassic Valley splits and sends three arms in north-westerly or northerly directions towards the sea. The most westerly of these arms is about 20 miles in breadth and is drained by the river Manambao, which, however, does not make use of the valley in order to reach the sea, but cuts straight through the northern end of the escarpment forming the Bemaraha. There is only one other locality in Madagascar where the Triassic rocks push through in this manner to the coast, and that is further north at Nossi-Bé, where again they are associated with an axis of Archæan rocks exposed by some folding movement which has again brought up the old gneissic floor.

Two of the Triassic branch valleys run almost due north round the margins of two Archæan islands, gneisses and schists, which come to the surface along the axis of the gap. They belong to the gneissic mass, of the Bongolava, but are separated from it, and are at a lower elevation. Again, as at Nossi-Bé, the gneissic floor, dropped down by the faulting at the edge of the Bongolava, is brought to the surface along an axis of uplift. Other branch valleys run round vast areas occupied by volcanic rocks, lava flows and great extinct volcanoes. In fact. the whole of this breach area has been one of violent vulcanism. Extinct volcanoes with craters sometimes many miles across, lava flows, dykes and sills, riddle the whole of the area and especially at the junction between this valley system, near the post and village of Morafenobe. A curious fact is, that the volcanoes are nearly always arranged in pairs, lying along a north-west, south-east axis, that is, parallel to the axis of the breach, and always one of the pair is a crater and the other a well developed cone. In other words, one was explosive and the other effusive. The Triassic rocks in this gap are in places heavily charged with petroleum, sometimes containing quite high percentages of the lighter fractions. South of the gap the Triassic Valley has been running almost due north and south. Here both the valley and the edge of the plateau swing east, then east-north-east and finally north-north-east, the normal direction of the axis of the island. Innumerable dykes cut through the

sedimentary deposits in all of these valleys, and some were noted cutting right through to the top of the Jurassics, and possibly the Cretaceous. In the French geological maps these dykes are shown running universally in the direction of the valley. This is not so, a great many run in varying directions across the valley.

(*c*) *The River System.*—The River System of Madagascar is of great interest. The rivers flow radially from the central gneissic plateau. On the eastern side of the island they are comparatively short, swift flowing streams, tumbling from the heights in innumerable cascades through steep rocky channels. As a rule, they do not cut far back into the gneisses.

The larger streams all flow to the west and sometimes cut nearly as far back into the plateau as the top of the eastern precipices. These rivers often reach the western edge of the plateau in valleys which hang high above the Triassic Valley, entering the latter by cascading through deep and narrow gorges. At the base of the Bongolava, such rivers are usually entered by subsequent streams which run parallel with the axis of the valley, often quite near to the foot of the precipice. This, of course, would be expected from the structure of the valley. The main streams cut across the valley and pass, by steep and narrow gorges, straight through the Jurassic escarpments. It is clear that these streams are exceedingly old, older than the Triassic sediments on the floor of the valley, and far older than the Jurassic escarpments. Taking the River Manambolo as an example, this river rises well back on the plateau, flows directly west through a hanging valley as a consequent stream, tumbles through a steep ravine in the face of the Bongolava which is piled with boulders and debris, is joined immediately by a subsequent stream which is flowing due south down the Triassic Valley, turns and follows the line of this tributary to the south for a few miles, meanders across the valley, and then turns due west again, cutting directly through the Jurassic escarpment in which it forms a rock-bound gorge, and from this enters the sea. But if we go straight across the Triassic Valley from the point at which the Manambolo emerges from the Bongolava, a great U-shaped notch will be noted in the top of the Jurassic escarpment at this point. Climbing the escarpment, we find that from this notch runs a valley, wide, deep and dry, which is beheaded by the escarpment. This is undoubtedly the ancient valley of the Manambolo, dating back to a time when no Triassic Valley existed, and the rivers ran directly from the high tablelands of the interior, down the dip slope of the Jurassic sediments which then abutted directly against the gneisses. A very pretty study bearing upon the



GNEISSIC PLATEAU WITH GRANITE DOMES.

DESCENT FROM BONGOLAVA INTO TRIASSIC VALLEY.

LIMESTONE CAPPED JURASSIC ESCARPMENT FROM TRIASSIC VALLEY.

TYPICAL SAKALAVA MAN.
(MESSENGER CARRYING OFFICIAL LETTER IN CLEFT STICK).

functions of denudation and geological time could be based on this river.

In the northern part of the island the streams run to the north-west, and in the southern part to the south-west. The river system in general throws a good deal of light on the structure of the island and its geological history.

It is interesting to note that the smaller tributary streams on the western side of the plateau appear to have started to cut further back into their water-sheds quite recently. The distinction between these newly-eroded heads of valleys and the older limits of the valley courses is very noticeable.

(*d*) *Glacial Phenomena.*—We were surprised to find abundant evidences of prolonged glaciation on the western side of the Archæan Plateau. Terraced moraines, perched blocks and rounded and worn hummocks abound in some of the valleys. Just west of Tsiromandidy is a valley several miles in width with great mountain masses on either side, which is filled with moraines. Blocks and boulders of all sizes are confusedly mingled together. Seven terraces were noted in this moraine material, all descending to the west, evidently marking stages in the retreat of a glacier flowing westward from the higher ground which forms the central part of the Archæan areas. On the north side of the valley is a mountain called "Bevato," which means the stony mountain. The side of the mountain is covered with huge boulders, perched blocks which are quite unmistakable. Similar phenomena were noted elsewhere, especially near Mianarive at a much higher elevation. The age of these deposits is doubtful, but in spite of their comparatively recent appearance we are inclined to think that they belong to the Permo-Carboniferous glacial period, for we have seen and know how fresh-looking are the boulder clays and glaciated pavements of this age which occur in South Australia. These look every bit as new and as well preserved as occurrences of the same kind which can be seen in Northern England, but which belong to the much more recent Ice Age.

(*e*) *Lateritic Deposits.*—Lateritic clays cover so much of the surface of the island that they call for mention. Professor La Croix[1] says that they are "the uniform result of the decomposition of all silicate rocks, no matter of what original mineralogical composition. This decomposition consists essentially in that the silicates have lost their alkalis, lime, and magnesia and part or whole of their silica." They do not form muds under influence of rain, and streams run over their surface without cutting deeply

[1] *Revue Scientific*, 24 juillet—14 aout, 1920.

into them; all that happens is that the surface becomes like that of damp soap. They cover most of the gneissic plains, but were noticeably absent from the large granitic outcrops and in some cases where schists and quartzites occurred. The thickness of these deposits is sometimes very considerable, upwards of 200 feet having been observed by us. It is probably much more in places, and all of this has been derived from the decomposition of the underlying gneissic floor. The surface bakes very hard in the sun, but a curious thing is happening to-day. Owing to the growth of the pastoral industry and the moving of cattle across the plains, tracks cut by many hoofs pierce the hard upper crust; the heavy occasional rains are in this way enabled to cut away the softer underlying material, and great holes and ravines quickly follow.

These lateritic deposits are not confined to the areas occupied by metamorphic rocks. Deposits of a similar character were found overlying sedimentary strata, especially in the Triassic Valley, though they were neither so extensive nor so well developed as on the plateau.

III. Peoples.

It is surprising to find that Madagascar has been peopled, not from Africa as we should have expected, but by waves of migration from the Indo-Malayan Area. There is practically no African element on the island, such as there is consisting mostly of descendants of slaves and of Arab traders.[2] and [3]

The actual invaders must therefore have crossed thousands of miles of ocean in frail native vessels and with limited stores of provisions. That such a feat is possible is proved by the fact that several Malay junks, caught by storms off the Sunda Islands, eventually made land at Tamatave in 1808.[4]

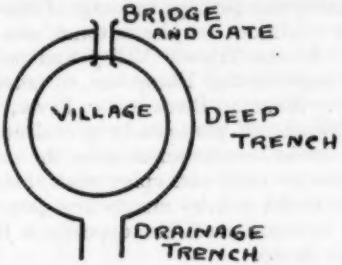
The predominant race on the high Plateau have the appearance of pure Malays. These are the Hovas, around them are grouped tribes of darker and sometimes of more negroid appearance, the most important of these being, perhaps, the Sakalava who inhabit the valleys and plains to the west. These peoples are

[2] "Madagascar," Guillaume Grandidier, *Geographical Review*, N.Y., 1920, vol. x., No. 4, pp. 205–209. Also "Ethnographie de Madagascar," Paris, 1908, 1914–1917, Alfred and Guillaume Grandidier.

[3] Some evidence has been brought forward to show that Madagascar had an aboriginal population related to the Bantus, though this is not yet generally accepted by French writers. See Emil Berkeli, *Journ. African Soc. Lond.*, 19, 1920, 305–316.

[4] A. Grandidier, "Ethnographie de Madagascar," vol. 1, pt. 1, pp. 8-10.

all of ethnographic types which indicate an Indo-Asiatic origin. Incessant tribal warfare has raged between these peoples for generations. On the western side of the Plateau between Fenoarive and Miandrivo we were much interested in a valley area in which fortification by means of trenches and rough walls has been carried out with very elaborate system. The villages were protected in a most remarkable manner. A wide and very deep trench, perhaps 20 ft. wide and as much as 60 ft. or more in depth, encircled the village, entrance being possible only by means of a bridge, usually consisting of a single stone slab, leading to a protected gateway also of stone. The lowest part of the circle was cut away by a large straight trench which drained the circular trench and possibly formed another means of communication with the enclosed village.



I have not been able to discover any previous description of these works and only one reference to them, that consisting of a very inadequate photograph unaccompanied by letterpress in a recent French work on Madagascar.[5]

The flora and fauna of Madagascar also differ very greatly from those of the neighbouring continent. None of the dangerous beasts of Africa, not even the venemous reptiles, exist on the island. We saw a few snakes, but they are said to be harmless, cases of snake bite being unknown. Crocodiles do constitute a danger in some of the rivers and swamps, even well up into the margins of the Plateau. It is our belief that small mammals and many birds which have never been described live in some of the wilder parts of the country. Even the fossil contents of the sedimentary rocks show greater affinities with Asiatic than with African forms. Near Tulear, at the southern end of the island, a Glossopteris flora and associated fauna have been obtained from beds containing coal-seams, forming the floor of the Triassic Valley. This links up

[5] A. Dandouau, "Geographie de Madagascar," 1922, plate XVII., p. 29.

Madagascar with the old foundered continent of Gondwanaland, but since this continent broke up Madagascar seems to have been entirely cut off from Africa.

IV.—Climate.

Travel is only possible over the greater part of Madagascar in the dry season. The climate is, like that of all regions around the Indian Ocean, monsoonal. On the east coast, however, heavy rains fall at all times of the year, the yearly rainfall at Tamatave being well over 100 inches. On the western side of the island the wet season extends from October to April, the time of the north-west monsoon, the rest of the year being almost continuously dry, and, lying within the Tropics, comparatively but not unpleasantly hot, excepting perhaps in parts of the Triassic Valley.

On the Plateau conditions are pleasant and, as a rule, healthy all the year round. In the Triassic Valley and on the west coast generally it is dangerous for Europeans to travel at all during the rainy season. Malaria, Black-water Fever, Dysentery, and other tropical plagues are particularly prevalent and pernicious. In any case, the tracks become impassable, the streams dangerous and the vegetation so rank and spiny that travel is impossible. In the extreme south the country merges into desert with very little rainfall. In the extreme north the opposite is the case and the climate is always damp.

V.—Travel in Madagascar.

Taken as a whole, Madagascar is not an easy country to travel in. It is sparsely populated, having less than three million people in a country larger than France (and about three times as many cattle). The greater part of the population tends to concentrate around the capital and other large towns and the seaports. There is only one comparatively small railway system and very few good roads, actually fewer than are indicated on some of the official maps. Most of these, again, centre on the capital. The rivers do not lend themselves to navigation. Canoes and even small launches can be used during parts of the year on some portions of the western rivers, but personal experience of such navigation proved it to be a hair-raising business. Moreover, with the exception of the bullock, there are very few beasts of burden in the country, and, therefore, few carriages excepting the rather rare horse drawn vehicles to be found in the larger towns, and these are now in competition with the cheaper kinds of motor car. Rickshaws are to be had where Europeans congregate but the nature of the

country prevents such vehicles from going far and so they are not much used. Bullock carts are used by peasants in a few favoured localities and bullocks are sometimes trained to the saddle. All such methods are foreign to Madagascar. When the native travels he walks or, if he can afford it, uses the "filanzan." This is a chair attached to two poles and is borne on the shoulders of four bearers. For any expedition a double crew of bearers is needed for they work on a curious system of quick changes. We found that, on an average, one set of bearers travelled for 120 paces and then changed over to the other crew without losing step or delaying progress. These men are as sure-footed as goats both in crossing streams or climbing or descending through steep and rocky country. We never saw one fall during six months of continuous travel, but we did see one of ours catch a fish with his toes as he waded through a considerable stream and that without holding up the party.

Provisions, sleeping kit with strong mosquito net and a medicinal and first-aid outfit, etc., are borne by additional carriers so that a fairly large retinue is needed for long journeys. The officers in charge of the military posts are very hospitable as a rule and so are the Malagasy villagers themselves. A rest-house or a spare house of some kind is always placed at the disposal of the European traveller. The wages required by the men are low, averaging little more than one franc per day, and out of this they provide their own food as they pass through the villages. The cost of travelling, therefore, is not excessive.

VI.—Geology of the Oil Bearing Areas.

(*a*) *General.*—Having thus given some general idea of the island we can turn to that part of it in which oil sands and seepages of petroleum occur. This is an area on the western side of the island extending from the neighbourhood of the River Manambolo and the town of Ankavandra, about 21° S. of the equator, to Cap St. André 18° S., a distance of about 200 miles. All the important impregnations of petroleum so far observed occur in the Triassic Valley between these limits.

The accompanying geological sketch map, which is the result of studies made in the field, differs very considerably from the existing maps. Further detailed work will result in even greater modifications of these maps, so that the boundary lines between formations are regarded as approximate and tentative only.

Extinct volcanoes, lava flows, dykes and sills are much more numerous and cover greater areas than is shown, although in this

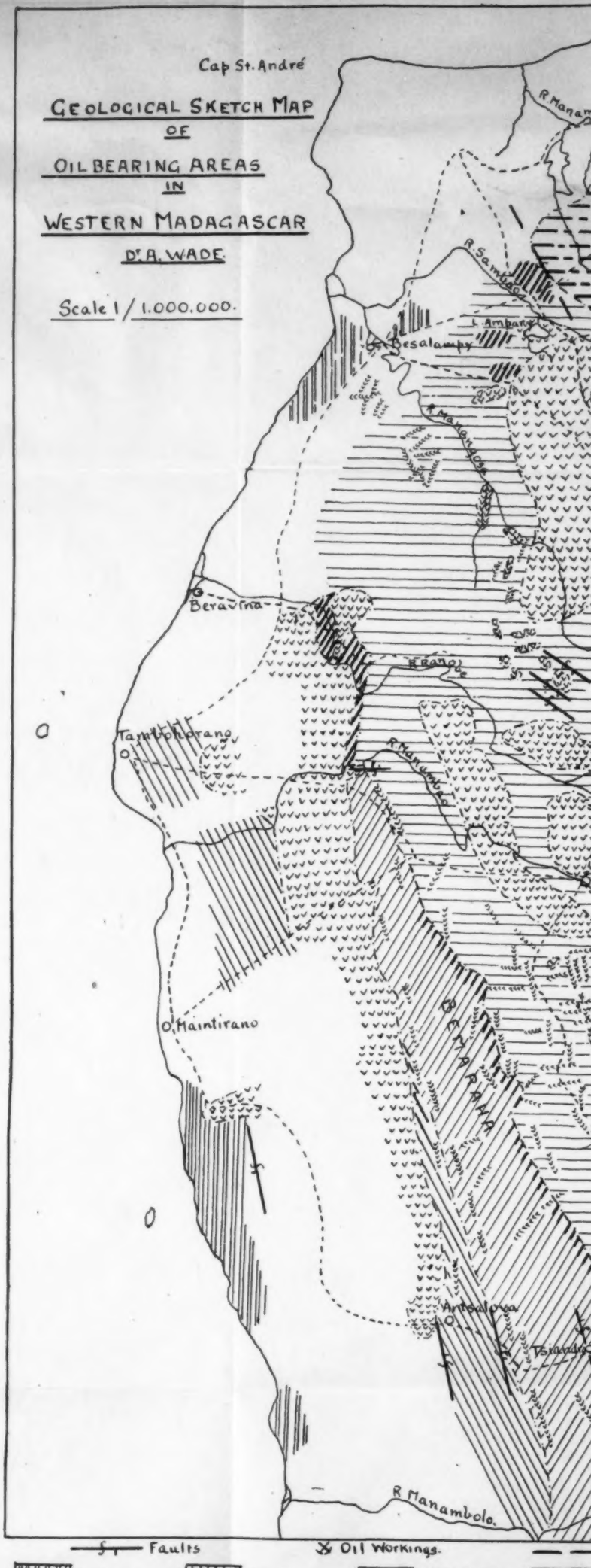
respect the present map is much nearer to the truth than the older ones.

To get an idea of the structure of the island and the sequence of formations a complete traverse was made from E. to W. Of this traverse only part is now relevant, that extending from the Bongolava, through Ankavandra to the W. coast. The sequence is as follows :—

Formation and thickness.		Nature of strata.	Fossils.
Quaternary.. ..	19.	Brick earth and Lateritic deposits. Recent beach and lacustrine sediments.	Fragments of the eggs of Aepyornis
Tertiary	18.	Coral sands and loosely consolidated limestones. More compact and massive limestones. (Eocene.)	Corals, sea-urchins, shells. Numulites.
	17.	Dykes, sills, flows and extinct volcanoes.	
Cretaceous. 1300 ft. Antsalova Beds. (Shallow water deposits.)	16.	Baked grey shales.	
	15.	Dolerites with large quartz and chalcedony geodes—sill.	Alectryonia ungulata.
Aturien	14.	Hard quartzitic and pebbly conglomerates. (Unconformable junction or fault.)	Gryphea vesicularis.
Cenomanian ..	13.	Alternating olive green clayey sandstones and shales.	Turrilites. Dinosaur remains.
Albien	12.	Red and pink sands, very fine soft and impalpable above, coarse and conglomeratic towards base.	Ceratodus. Duvalia dilatata.
	11.	Olive green shales	Baculites. Belemnites, Belemnopsis, c.f. hastatus.
Upper Jurassic. 350-450 ft. Tsiandro Beds. (Shallow marine. Fringing coral reefs.)			
Callovian ..	10.	White marls with impure limestone bands.	
Bathonian ..	9.	Massive grey limestones with corals above, containing coarse quartz and pebbles towards base.	Corals. Ammonites. Brachiopods, Rhynchonella concinna. Lamellibranchs. Echinid spines.
Bajocian ..	8.	Coarse, red grits.	

Formation and thickness.	Nature of strata.	Fossils.
Lower Lias & Upper Trias. 1400 ft. Berano Beds .. (Continental type of deposits.)	7. Fine white sands with well-worn and rounded grains, finely powdered material. White grits with wind-facetted pebbles.	Silicified trees.
	6. Coarse sands with some chocolate and green clays, beds of chert, some partings of black carbonaceous shales.	Ammonites.
	5. Fine green sandstone with bands of chocolate and green clays, 4 ft.—6 ft. thick.	
	4. Very massive false bedded sandstones with layers of conglomerate and coarse quartzitic grit 100 ft. thick. This conglomerate consists of boulders derived from the Bongolava.	
	3. White sands with bands of red clay 3-4 ft. thick. Whole series 50-150 ft. thick. Oil seepages and tar sands occur in these beds. Unconformable junction.	
Lower Trias. 1000 ft. Ankavandra Beds. (Shallow water deposits. Fluviatile)	2. Thick beds of impure micaceous sandstones, false bedded with thin shale bands. Some layers of coarse grit vary from a dirty tan colour to greenish grey and brown.	Estheria c.f. minuta.
	1. Very finely bedded micaceous shales with thin impure sandstone bands and some thin concretionary limestones. Thin conglomerate bed. Oil seepages and tar sands occur in these beds to the north of the section line, coal to the south.	Small lamellibranchs.
Permian	Sandstones, shales and conglomerates with coal. Not seen in this section, but may be overlapped in the valley. Crops out to the south.	Glossopteris and allied flora.
Archæan	Augen-gneisses. Quartz-mica schists, etc.	

The general strike of all the sedimentary strata observed in this section is approximately north and south. Normally they


Cap St. André
GEOLOGICAL SKETCH MAP
OF
OIL BEARING AREAS
IN
WESTERN MADAGASCAR
Dr. A. WADE.
Scale 1/1.000.000.
R. Manan
R. Sambao
L. Ambary
Besalampy
R. Manambaho
Beravina
R. Ranoa
Tsimbohiranno
R. Manambolo
O. Maintirano
Antsalova
R. Manambolo.
Faults
Oil Workings.
Tertiary.
Cretaceous.
Upper Jurassic Massive Limestone.

L. Kinkony
R. Manambo
Bekodoka
R. Sambao
IKAHAVO
Ambatomainty
Sembanga
Morafenobe
Folakara
Marolevaly
Soalaka
R. Manambolo
Aakavandra
Berano
Tsiandro
Great Fracture Zones
Lower Lias and Trias
Volcanic Rocks
Dykes, Sills, Flows
Schists etc.
Gneisses
Archa

dip very gently to the west, seldom reaching and rarely exceeding 10 deg. Some of the estimated thicknesses may have to be modified owing to the presence of strike faulting. Some duplication due to this cause was observed in the sequence especially in the vicinity of Antsalova, and possibly near Tsiandro. Dykes were observed cutting through all these beds up to the top of the Jurassic, standing out from the whole face of the escarpments. They probably out through even higher beds and connect with the sill which has been intruded into the Cretaceous. The evidence suggests that the whole of this volcanic activity took place in Tertiary times.

Seepages of oil and outcroppings of tar sands occur in the Triassic Valley from the neighbourhood of Ankavandra northwards to the great nodal area where the valley splits into five arms. It is interesting to note that these seepages and outcroppings increase in importance as we proceed northward from Ankavandra and culminate in an extensive area of exposed oil sands at the junction of the valleys. At the same time the prevalence and size of volcanic dykes increases in the same direction until we find this oil sand area encircled by great extinct volcanoes and flows of lava.

A good deal of exploratory work for petroleum has been carried out in this area, in the valley itself by British companies, at the junction of valleys by French companies, all so far without achieving commercial success.

(*b*) *Ankavandra Area.*—Seepages of petroleum are reported to occur in the neighbourhood of Ankavandra, but we were unable to find anything of importance in this district, though some thin coaly layers were found in beds belonging to the Berano Group. The strata forming the valley floor are, however, folded, the folding being more pronounced in the Ankavandra beds than in the Berano strata, that is, the beds become more affected by such movements the nearer we approach to the Bongolava. The folds run approximately in the direction of the valley, *i.e.* almost due north and south. It is evident, therefore, that such folding is due to pressure from the west, the strata having been slightly compressed against the Archæan horst. Some further proof of this was noted about six miles from the north of Ankavandra where strike faulting was observed to be of the nature of a thrust to the east, the beds of the Lower Lias and Upper Trias being locally thrust over Lower Triassic Strata at this point. Ankavandra itself stands upon a syncline in the Ankavandra beds, the river Manambolo to the west of the town running almost due south near the crest of a corresponding anticline. Dips vary between 5° and 20°, the steeper dips being to the east. Another anticlinal fold comes in to the east of the

Ankavandra syncline between the town and the wall of the Bongo lava. The massive grit of the Berano group has a westerly dip of about 5° at the outcrop near the village of Berano, but even this dip becomes smaller and the grit is almost flat at the village itself.

The overlying Jurassic strata forming the escarpment are very flat, the westerly dip being very small indeed. Thus the folding in the beds is inconsiderable except near where the strata abut against the Archæan mass.

The whole sequence is well exposed which was surprising since we had been told that the difficulty in this part of Madagascar was the scarcity of outcrops. Strike faulting is also more prevalent than has been noted by earlier observers. The folding observed at Ankavandra can be traced about 6 miles to the north of the town where the more easterly anticline is better exposed. The strike here is N. 15° W. (mag.). The Ankavandra Syncline is also present, the dip to the east being 5°, while 200 yds. further east the beds are dipping west, steepening rapidly from 5° to 12°. About 1 mile north of the site of Old Ankavandra the Archæan juts right into the plain as far as the river Manambolo swinging back again to north and south. Here, in front of the normal Archæan precipices the gneiss appears again in low rounded hills with little elevation above the Triassic floor of the valley. This is an exposure of part of the gneissic floor, which must underlie the whole of the island to the west and pass beneath the Mozambique Channel. Other exposures of this gneissic floor have been referred to, but almost everywhere else it is buried beneath the sediments. It enables us, however, to measure approximately the downthrow in this area and shows that the Triassic cover is here very thin, though it thickens to the west. Confirming this we found coarse sand and conglomerate only a few feet thick coming from beneath the shales of the Ankavandra beds and resting directly on the Archæan. This is the basal member of the Trias in this area. The actual fault zone in the Archæan is here exposed. Gneisses and schists are jumbled together in a shatter zone, but along with them we found patches of shale, partly metamorphosed, and resilicified conglomerate, which suggest that the basal beds of the Trias have been caught in later movements along this fault zone. The greater part of the fault movement is, however, pre-Triassic and from evidence obtained further south pre-Permian. Basic dykes intersect this shatter zone, one large dyke running due west from the area across the valley, while smaller ones run to north and south.

(*c*) *Maraboaly Area.*—Sixteen or seventeen miles north-north-west of Ankavandra is the village of Maraboaly. West of this village is a small seepage situated on the west bank of a ravine. Thick

heavy oil, together with a little water, is oozing from the beds. It is coming with the natural drainage from a bed of grit about 1 metre thick, which forms the surface and is here exposed. About 1½ miles to the east, against the dip of the bed, which is very small, another ravine exposes the same grit from which similar material is again seeping at the junction with underlying shales. A strike fault running north and south at this point cuts off the grit and throws it down to the east. A good deal of drilling for oil has been done in this area, so that it will be well to consider the existing structural conditions.

A few miles due east of Maraboaly is the village of Soaloka, wrongly shown on some of the geological maps as standing on the Archæan. Instead of that, there is a narrow anticline in the Ankavandra beds between the village and the Archæan, the dips on each limb are small ranging from 3 to 5 degrees. The beds flatten in the neighbourhood of the village, but the axis of the corresponding syncline is to the west, further west than is shown by Evesque[6] (*Chef du Service des Mines*), in his map of this area. About two miles further west, again further west than is indicated by Evesque, a well-defined symmetrical anticline is well exposed, running almost due north and south, the beds dipping at from 7° to 10° on both flanks. The axial portion of this anticline is exposed for a distance, east to west, of at least 1 kilometre, though the dip to the west continues, with some interruptions by dykes and faults, as far as Maraboaly. One of these dykes carries on its side a layer of baked shales right through a hill of sandstones, in which no shales are exposed, and without otherwise disturbing the strata. It is remarkable that, with all the drilling done in this area no attempt was made to test the above structure, which is ideal from a tectonic point of view. Moreover, the strike fault, mentioned in connection with the second oil seepage, throws down the bituminous sand which is not exposed by the cutting away of the beds in the broken crest of the anticline. The bores are well to the west of this area and are grouped around the two seepages. Evesque shows another " probable anticlinal axis " to the west of the bores, but no trace of such a structure could be found, the beds flattening considerably to the west as they do in the Ankavandra-Berano area, folding dying away in this direction. Dykes are more numerous in this area, and here it was we began to note that where dykes are absent or of rare occurrence we found no evidence of bitumen.

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[6] *Etude sur les Hydrocarbures de l'ouest de Madagascar. Bulletin Economique de Madagascar, Deuxieme Trimestre,* 1921, p. 24.

TRAVELLING BY FILANZAN ON CENTRAL PLATEAU.
GRANITE KNOBS IN BACKGROUND.

ON THE MANAMBOLO RIVER.
TRIASSIC VALLEY.

VOLCANIC MASS OF AMBOHITROSY FROM THE S.
SHOWING CONES AND CRATERS.

CARRIERS LEAVING AMBATOMAINTY.
BONGOLAVA IN BACKGROUND.

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Six bores were sunk at Maraboaly. They test a small area 6 kilometres from north to south and 3 kilometres from east to west. The logs of the bores, so far as they have been preserved, are given by Evesque in the paper referred to, but they are of little value, since every driller has a different name for each formation penetrated and correlation is impossible. A few brief notes on these will suffice:—

Bore No.	Metres.	
1	98	Lost.
2	255	Drilled close to No. 1 after this was abandoned. Nothing of interest recorded.
3	800	Showings of oil at 314 m., 441 m. and 727 m. Bottom in shale.
4	858	Showings of oil at 736 m. and 810 m. Bottom given as red, sandy clay. Evesque states that this log is unreliable, and that the workmen told him that the bottom formation was so hard that it broke the bit every time it was run. He thinks that they either bottomed in basalt or in the Archæan. Undoubtedly it was the Archæan. Not only does "red sandy clay" suggest "gneiss" but basalt drills fairly readily though slowly, whereas, in my experience, gneisses and granites are great bit breakers with cable tools. Moreover, this is just about where we should expect to find the old gneissic floor, which evidently slopes to the W., the Triassic sediments above thickening in this direction at the same time. This may be an important point to note if any further search for oil is carried out in Madagascar.
5		No log. Hole lost.
6	635	Showings of oil at 96 m. oil sand 6-7 m. thick. " " 125 m. " 17 m. " " " 295 m. " 3 m. " " " 596 m. " 14 m. " " " 620 m. " 25 m. " " " 632 m. " ? " This hole appears to have been drilled without care being taken to shut off water. An attempt was made later to cement off water in order to test one of the upper sands, but there is no record to show how successful this operation was.

The logs show that a number of oil sands exist below the surface in this area. One is inclined to wonder what the results would have been had these wells been more favourably placed with regard

to structural conditions. A good deal of boring plant remains on the ground, but no work has been done now for many years.

(*d*) *Folakara Area.*—About 20 miles, again to the N.N.W., is the village of Folakara, a quaint, primitive but pleasant cattle village standing on a hill. Between Maraboaly and Folakara strata of the Berano type occur dipping to the W. at very low angles with few exceptional and local reverse dips to the east. Dykes are numerous and of large dimensions, forming ridges where unweathered, trenches where for some reason or other they have decomposed. They cut the country up into rough rectangular blocks, for those running east and west are quite as numerous as those running N. and S. One large dyke, 50 metres broad, cuts across country for miles in an E. and W. direction.

One very interesting feature observed in this area is the abundance of fossil trees preserved in silica, weathering out of the surface beds, probably from the top beds of the Berano group before the strata numbered 7 in the section and which were laid down in desert conditions come in. Here are great whole trees, some as much as 100 ft. in length and 4 or 5 ft. in diam., well preserved even to the stumps of the branches. Some of these trees are intact, others have broken into cylindrical segments. Nothing of this kind was noted further south, though fragments of silicified wood were observed at about the same horizon.

About 2 miles to the N.W. of the village an outcrop of grit forms a cliff about 20 ft. high, which is impregnated with bituminous matter from top to bottom. It is an exposure of a typical tar-sand. At the base of the cliff is a small spring, the water carrying with it a very viscous black oil which is concentrated all along the base of the cliff and is actually flowing where the water facilitates movement. The section is :—

	Feet.
Variegated clays	10
Very soft grit, impregnated with bitumen	20
White sandstone	3
Variegated clays	6

Above, the beds are cut through by an east and west dyke, 6 ft. in width, near which a bed of black carbonaceous shale, 3 ft. thick, outcrops. Green clays and another massive grit are exposed in the hill above, but no trace of bitumen was found. A second dyke was found, following a line which would carry it along the base of the cliff where the seepage occurs. Fifteen other dykes were counted in the immediate vicinity, mostly running E. and W. One, 12 ft. wide, forms a trench with vertical walls of grit hardened by heat and secondary silicification. The beds on the north side

are tilted at very high angles. It is a curious fact that these E. and W. dykes, which are becoming more numerous as we proceed north, appear to be the only ones which have any marked effect upon the strata into which they are intruded. Torsion of the crust in their vicinity is suggested by the behaviour of some of them, for they often make abrupt changes in direction when they are traced for some distance.

A mile to the N.E. of this occurrence is another seepage, again at the base of a cliff of what is more appropriately called a sandstone in this case. The bed is soft and friable and not so uniformly charged with bitumen, though the outflow from the strata is considerable.

When these impregnated grits and sands are traced for any distance it is found that the bituminous content is very variable. In many places they appear to be quite free from such matter, though in other localities the area and extent of impregnation is impressive. There is not much in the way of structure in this area. The beds lie very flat, and where dips are measurable they are to the W. Some strike faulting is again evident, so that a sequence of strata may be duplicated in a short traverse. The strata belong to the lower Berano sequence, and in this locality the grits and sandstones show themselves to be in great lenses which come in sporadically, thicken and become important locally and then thin out again as they are traced across a section of country. Folakara is apparently too far west to be influenced by the folding caused by pressure of the beds against the wall of the Bongolava. Boring has, therefore, been undertaken here chiefly on account of the seepages and the important outcroppings of tar sands. Seven bores were put down by a British company in this area :—

Bore No.	Metres.	
1	274	Showings of oil at various horizons, chiefly at 150 m. No log preserved.
2	295	Showings of oil and gas at 128 to 135 m. " " 144 to 157 m. " " 235 m. " " 286 to 295 m.
3	386	Close to Nos. 1 and 2. Section similar to No. 2.
4	480	Showing of oil and gas at 215 m. Log not considered trustworthy.
5	180	Lost.
6	210	Close to No. 5. Showing of oil at 180 m.
7	133	Again close to Nos. 5 and 6. Log quite different, which, Evesque ironically explains, is due to the fact that a different driller was employed.

All these bores met with oilsands. One is said to have obtained a light, brown oil at depth. Although the structural conditions in this area are not altogether promising, boring having been decided upon, it looks as though one deeper test would have revealed more than these seven comparatively shallow bores have done altogether.

(*e*) *Morafenobe-Bemolanga Area.*—North of Folakara nothing of special interest was seen for between 30 and 40 miles. Strata of the Berano type still persist and, being almost flat, any oil sands which may lie below the surface are effectively hidden. Dykes increase again in number and in size, and are now accompanied by actual surface flows of lava. An interesting feature in connection with some of the dykes observed in this traverse is that they never came to the surface. Instances were noted where the sandstones were pushed up into sharp ridges, which showed nothing at all excepting where cut through by a stream which revealed the presence of a dyke in the core of the ridge. In one case the ridge had a low wall of sandstone running along its crest. Where this was broken away the dyke showed through. Where it had weathered away the dyke had weathered away also, so that in place of a wall there was a narrow trench, lined with decomposed basalt, running along that part of the crest of the ridge.

The military post and village of Morafenobe stands near the centre of the junction of Triassic valleys. About 9 miles to the N.E. is the village of Bemolanga. Around these two villages is a country of great structural and geological interest. The sedimentaries belong again to the Berano series, massive grits, red and green clays and soft white sandstones predominating. It is an area of intense vulcanicity. Great circular walls of old volcanoes, small volcanic vents which look as if they had been active yesterday, their walls being formed, in part, of the adjacent strata, pushed up, but remarkable in the fact that they seem to have been affected very little by heat; vast cones and plugs, often in pairs, one being of the effusive and the other of the explosive type, as though there had been alternating action in sympathy, all orientated on a N.N.W. and S.S.E. axis or parallel with the axis of the Cap St. André Archæan peninsula; these surround the area of sedimentary rocks of which Morafenobe and Bemolanga are the centres. Even this area is riddled with dykes, which are best seen around its margins. It is an area of uplift above the normal level of the Triassic valleys and the Trias and immediately overlying strata appear to be thicker in this area and right through the gap to the coast than was observed elsewhere.

About 10 or 12 miles S. of Morafenobe the strike of the strata begins to change to N.E. and N.W., the beds dipping away from

the elevated area around Bemolanga to S.E. and S.W. Strike faulting and dykes appear to form concentric circles around the uplifted region. Dips steepen and a line of outcrops on this southern fringe could be traced a long way across country with dips of as much as 30° and 40° to S. and S.E. A low anticline was seen in the massive grits just W. of Morafenobe, but it is in close proximity to a great volcanic mass and no trace of bitumen was found in the beds. In the centre of the region of uplift around Bemolanga the beds are almost, flat though there is a slight regional dip both to N.E. and N.W. Thus the structure of this area is that of a great flattened dome, assymmetrical, the steeper dips being on the southern margins. Evesque claims that anticlinal folds cross the region, but we failed to find evidence of them. Professor La Croix, who paid a brief visit to this area in 1911, while making a study of the mineralogy of the island, agrees with our observations. He states: "These regions are not folded; the sandstone beds are almost horizontal with a slight dip to the west, or at least they may be folded with a large arc of curvature." [7]

The area held by a French concern at Bemolanga is very extensive, and comprises practically the whole of the region of uplift, which is occupied by sedimentary rocks. It is a wide and level plain underlain by massive grits. Pits and occasional exposed sections prove this to be over 60 feet thick, none of the sections showing the full thickness of the bed. Over the whole of this area the grit is impregnated with bitumen in varying degrees. It has all the characteristics of an oil sand in many exposures. Where such exposures are natural, and therefore old, it is black and tarry in appearance. Where it has been opened up in workings it is usually a coarse grit, bluish grey in colour, and is impregnated with what is practically a light petroleum. In places it becomes a fine grained sandstone still charged with oil. The oil contents are not uniformly distributed throughout the sand or throughout the area.

A few miles to the south of Bemolanga is a low escarpment in which the following strata are exposed:—

Soft sand and grit, intensely false bedded, bituminous in places. This is evidently the lower part of the oil-sand horizon, the upper part having been removed by denudation	20–30 ft.
Variegated clays, mostly greenish in colour	20–30 ft.
Massive grits, bituminous. Base not exposed	10 ft.

The only work which has been done by the French company holding the concession consists of the digging of pits and trenches and the

[7] "Mineralogie de Madagascar." Tome II. p. 186.

putting down of very shallow bores by means of a portable core drill in order to ascertain the thickness and nature of the oil bearing beds. The pits were all full of water when examined and this was sometimes covered with a scum of light oil. The work was abandoned and the place deserted in September, 1922. There has thus been no deep boring in this area. Taking into consideration the structural features and the fact that more than one oil horizon was met with in most of the borings put down in the southern areas it is rather surprising that some deeper test was not made by the company.

Apparently the first idea which the French engineers had was that by the digging of these pits the oil could be induced to flow and could be drained from the sands as at Pechelbronn. The oil, however, refused to leave the beds except in small quantities, the reason being that the oil sands were under practically no pressure whatever since they form the surface. Next, schemes were considered for extracting the oil from the sands by physical or chemical methods. Reports on such projects, written by French engineers, estimate the volume of bituminous sand available and the quantity of petroleum which could be extracted by such methods, endeavouring to show that such work could be done profitably. These estimates always seem to assume that the oil contents are uniformly distributed in these grits, whereas, as already stated, this is not the case according to our own observations. This, of course, would affect these estimates considerably. I believe that the work was subsidised by the French Government, but it has evidently proved a failure up to the present.

Evesque's report deals very fully with the question of mining these oil sands and even considers the laying of pipe lines to the coast and the construction of railways. He estimates that there are from 45 million to 60 million tons of impregnated sand available and that samples brought to France yielded 54 litres of heavy oil to the ton.[8]

M. Merle, another engineer, formerly in the employ of the Department of Mines in Madagascar and later with the Geological Survey of France, estimates that there are 1,000 million metric tons of bituminous sand available and states that the yield from good samples of fresh sandstone amounts to 100 litres of oil per ton[9] Even then the most optimistic figures as to financial returns upon the enterprise as worked out by Evesque only show a return of 5 per cent. on a large capital outlay.

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[8] Loc. cit. pp. 15–27. Also pp. 179–180.

[9] *Informations de l'Agence Economique de Madagascar.* Jan. 1st, 1922, p. 5. Feb. 1st, 1922, pp. 3–4.

(*f*) *Analyses of the Crude Oil.*—The following analyses are given by Prof. La Croix[18]:—

Nature of Samples.	Crude Oil. In litres to the ton of mineral dehydrated.	Light Oils. Per cent. in weight of the crude oil.			Heavy Oils. Lubricants.	Mazout. Residue.
		Gaso. 70° to 160°	Kero. 180° to 260°	Tot.	220° to 360°	
1. Asphaltic Sand ..	70	26·4	24·1	50·5	not separated from mazout	not given
2. Asphaltic Sand ..	100	13·1	34·5	47·6		not given
3. Compact Sandstone	60	6·0	12·4	38·4	36·4	25·2
4. Asphaltic Earth ..	257	6·7	43·9	50·6	37·1	12·5
5. Pissasphalt ..	660	3·3	23·3	26·6	40·0	33·3
6. Pissasphalt ..	700	7·0	12·0	19·0	72·0	8·0

Prof. La Croix notes with surprise that the heavy crude obtained from the sandstone is richer in the light fractions than the samples of asphaltic earth and the pissasphalt obtained from the surface seepages, but is not this to be expected, since the material which has escaped from the rocks in this manner would naturally be that which had been most exposed to all those conditions which result in oxidation and loss of light fractions?

(*g*) *Other Areas.*—Traverses were also made of the country to the N. and W. of this area, but though the whole of the country is full of interest both as to geology and physical geography and is worthy of description from both points of view, little need be said of it with regard to petroleum. A good deal of it is wild, unexplored country with a high divide coming between Morafenobe and Besalampy on the coast. Massive grits rise in steps to this divide and on the dip slope towards Besalampy there is evidence of anticlinal folding on a considerable scale. The area is, however, riddled with volcanics and volcanoes.

About the crest of the divide the grits have been baked, silicified, jointed and weathered till the remnants stand out in isolated blocks, carved into fantastic shapes, which look like a forest of weird statues. In the valleys volcanics always occur and there is evidence that the whole of this dip slope is underlain by a sill or sills which have been intruded over a vast area.

M. Perrier de la Bathie, Government Naturalist and Geologist in Madagascar, has made a report on the petroleum situation which

[18] Op. cit. Tome II., p. 187.

had not been published at the time of our visit, or since so far as we know, but which we had the good fortune to be allowed to see. It is a very able piece of work, and the author often reaches conclusions which conflict with those of other officials. He mentions the existence of petroleum in beds near the base of the Cretaceous, well down the dip slopes on the western side of the island and probably associated with faulting. Heavy petroleum was also met with in a boring made for coal by a private individual where the Triassic beds push through to the sea again in the breach at Nossi-Bé in the northern part of the island, but the amount was not sufficient to be profitable nor should we say, from a brief personal visit to the district, that the general conditions were such as to warrant further search.

VII.—General Structure of Madagascar.

An interpretation of the general structure of Madagascar is necessary before dealing with the question of the origin of the petroleum and prospects in connection with future developments.

Dealing first with the Archæan, a persistent dip to the west was very noticeable in the foliation of the gneisses in most places where we could observe it. Between Tsiromandidy and the edge of the Bongolava we passed over a strip of country occupied by crushed schists and quartzites. Then followed the gneisses again to the edge of the valley. Later, while examining the Archæan islands surrounded by Triassic beds in the Cap St. André area, we found again schists on the southern and eastern sides of these and a very apparent crush zone. South of this the edge of the Bongolava has been taking a north and south direction up to a point just east of Bemolanga. Here it changes abruptly to east and west as far as Ambatomainty, where it again makes an abrupt change of direction to north-east. There are marked signs of disturbance and faulting in the Archæan in the re-entrant angle at Ambatomainty, and we then found that the line of fracture on the east side of the Archæan blocks forming the core of the Cap St. André peninsula would, if continued, not only connect with the faults in the Archæan at Ambatomainty but would also pass through the zone of crushed schists and quartzites near Tsiromandidy. This line is traceable right across the valley at Ambatomainty from the Bongolava to the Archæan islands, for it is represented by a broad and massive dyke which runs as a continuous and impressive wall along the line which the fault zone, here concealed under Triassic sediments, should take. Climbing to the top of the Bongolava south of Ambatomainty we found further confirmation of this in the presence of metamorphic rocks containing large numbers of well-formed

crystals of zircons and other secondary minerals which, weathering out, are scattered all over the surface. It is evident that this fracture zone which we have thus traced from south to north for over 200 miles is an overthrust from the west. The westerly band of gneiss has been overthrust eastwards on a line running almost north and south, a little west of north and east of south, over metamorphic rocks, schists and quartzites, which originally overlay the gneisses. We have now established over-thrusting along this line and this supports an impression we had formed that the whole of the gneissic mass of Central Madagascar is a gigantic overthrust to the east. The whole mass is cut off on the eastern side of the island by a normal fault which determines the remarkably straight and practically unbroken line, running N.N.E., south-south-west, which constitutes the east coast of Madagascar. Gregory states that the age of this fault is not earlier than Upper Cretaceous.[11]

The thrusting observed is much earlier and is probably very ancient, for we found patches of the Lower Lias resting on the Archæan in the faulted down blocks forming the axis of the Cap St. André area in such circumstances as to prove that these beds were originally laid down right across these Archæan islands and have not been considerably disturbed by faulting since. A curious feature here, is the course of the River Sambao. It rises in the Triassic branch valley on the eastern side of these Archæan islands, runs down the valley for some distance and then, in spite of the fact that there is now a perfectly good valley formed of soft sedimentary rocks to follow to the sea, it changes its course abruptly to the westward and cuts right across the hard rocks constituting the centre of the southern Archæan island. It is clear that the course of this stream is older than even the Triassic sediments—older than the movement which formed the Cap St. André axes but younger than the Bongolava fault.

Turning to the Triassic Valley itself, and especially to that part of it south of Morafenobe, the edge of the Bongolava runs north and south, and is determined by a line of faulting with a down-throw to the west which, as we have shown, is older than any of the sedimentary rocks lying in the valley. This fault is exposed near where the River Manambolo breaks from the Bongolava into the Triassic Valley. It has had little effect upon these newer sediments. Passing across the valley we find that near Antsalova the Jurassic and Lower Cretaceous beds have been affected by strike faults which run approximately parallel to the old Bongolava fault-line, but the down-throw here is to the east, so that if these

[11] *The Rift Valleys and Geology of East Africa.* 1921, p. 307.

later faults pass into the underlying Archæan also the effect is that the Archæan is trough-faulted, and it looks as if the axis of this trough-faulting is further to the west than the axis of the present trough-shaped valley. Near the coast M. Perrier de la Bathie has observed that faults, again taking directions parallel to the Bongolava fault, throw down Upper-Cretaceous and Tertiary beds to the west. Now what is the probable effect of this system of faulting? It seems most probable that all these faults in the sedimentary strata are simply later movements along ancient lines of faulting which are related to the faulting in the Bongolava. If this be so, the Triassic Valley is simply a young valley formed by the retreat of the sedimentaries from their original contact with the Archæan Wall owing to the usual agencies of denudation and superimposed upon an old structural valley in the Archæan, the superimposition being not yet exact. Further, a ridge of Archæan must come up under the Jurassic and Cretaceous beds between the Jurassic escarpment and the coast. In other words, the same kind of thing which is exposed by the breach in the Jurassics which constitutes the Cap St. André area continues under the sedimentaries all along the western side of the island. This is an important conclusion and may settle some difficulties. It is very evident that the Ankavandra and Berano beds thicken rapidly not only as we pass westwards from the Bongolava but also and to a much greater extent as we approach the breach area on the western side of the Cap St. André axis. Now these beds were formed very largely from material brought down from the Bongolava by such old rivers as the Manambolo and laid down over the depressed Archæan floor. Probably even this was still a land area exhibiting somewhat similar features to those existing to-day save that, instead of a Triassic Valley there was an Archæan Valley, an old "rift valley" parallel to the new rift valleys of Africa. Evidently a breach already existed in the Cap St. André area in the form of a depression in which the rivers from the Bongolava came together and, flowing to the north-west, piled up the thick deposits which now lie in this part.

The Cap St. André axis is due to a later system of earth movements which affected the Archæan. Folding along axes running north-west to south-east is discernible in the island. Three such folds can be traced, the most important being that which gives rise to the Cap St. André promontory. It can be traced from there right across the island. A less pronounced fold comes in at Nossi-Bé on the northern side of a Jurassic-Cretaceous basin, and a third runs across the southern part of the island and gives rise to the protuberance at Cap St. Vincent. A contoured map of the island shows that the Archæan plateau is divided into three

parts by this cross-folding, the age of which is at least pre-Permian.

The gneissic platform of Madagascar comes to the surface again on the African side of the Mozambique Channel, and here again beds of Triassic Age, which are reported to contain oil sands in places, have been observed along this part of the continental margin.

VIII.—Origin of the Petroleum.

The strata in which the seepages and oil sands occur are fluviatile or estuarine in origin. They contain in places a good deal of carbonaceous matter, thin coal seams and black carbonaceous shales. But, as we have stated, beds of Permian age, containing a Glossopteris flora, come to the surface from beneath the Trias at the southern end of the island, and in these beds coal seams are thicker and of more importance. It is possible that these beds extend further to the north and are concealed by the overlap of the Trias. If this was all that could be said on this subject, we should conclude by the deduction that the oil had originated from vegetable matter deposited with these beds. But, as we have observed, the great network of volcanic dykes which criss-cross the oil-bearing areas seem to have played a part. Where such dykes were absent or rare we found no seepages, no tar sands. Such seepages and tar sands become more important and prolific directly as the dykes become more numerous, until we get the greatest concentration of petroleum at Bemolanga, a region of intense volcanicity. This may be coincidence, though after examining these areas, we doubt it. It certainly appears as though the petroleum in these areas had been distilled from the carbonaceous matter present in the beds by the heat which emanated from the intrusives. We have noted that some of these dykes never penetrated to the surface, never even got quite through the Berano series. Others go through to the top of the Jurassics. Probably also there was a thick cover of Jurassic rocks overlying the areas at the time of intrusion, so that we get heat and pressure affecting the sediments and impervious beds of shale and clay forming an adequate protecting cover. We have reached the conclusion that here in Madagascar we have what may be an exceptional case of oil formation. Heat and pressure probably play their part elsewhere in causing petroleum to be formed in the strata, but in most cases they are due merely to the depth of the deposit below the surface. In this case, it is heat introduced by vulcanism. On a small scale, the association of petroleum with dykes is not unusual. The uncommon factor in this case is the extent, both as regards

area and the amount of petroleum produced. Possibly this mode of origin explains the peculiar fact that the oil at Bemolanga in sands forming the surface is often so light in character, for these intrusives are undoubtedly of Tertiary age, so that, if our theory is correct these sands may have only become impregnated during a comparatively recent period.

IX.—Future Prospects.

M. Perrier de la Bathie, whose work we hold in high regard, in his unpublished work considers that the areas most worthy of further consideration are:—

1. On the W. side of the Cap St. André axis.
2. On the lines of faulting separating the Eocene from the Cretaceous in the western part of the island.
3. On the lines of faulting separating the Cretaceous from the Jurassic in the same district.

No drilling or other active work has been carried out in any of these areas. The advantage in connexion with 2 and 3 lies in the fact that the oil-bearing strata of the Triassic Valley are here under cover of 1,500 feet or more of later deposits, including considerable thicknesses of clays. These areas are also within easy distance of the coast and there is no high plateau to surmount to reach them. Further, if our view of the structure of Western Madagascar is correct, the structural conditions should be favourable to accumulation and preservation of oil supplies in the underlying strata occurring in the districts indicated by 2 and 3. M. Bathie thinks that, owing to exposure, most of the petroleum may have gone from the beds in the valley. In these places any oil that may have accumulated is adequately protected. That such accumulations may have been formed is suggested by the fact that oil has been observed in connexion with these lines of faulting.

There is, however, yet a fourth area, and this has not been examined for petroleum. It lies towards the southern end of the island near where the Permian rocks and coal seams are exposed. There is some evidence that the Permian and Triassic sediments thicken considerably again here. It is said that dykes do not occur or are rare, and that anticlinal conditions exist. We are not able to confirm these reports, but it is possible that the area is worthy of attention.

X.—Conclusions.

We have thus glanced at the whole field of Madagascar from many points of view. A great amount of the information acquired by

us has been reluctantly omitted. As a field for geological, geographical and mining research we are convinced that few parts of the earth can offer more interesting problems for solution. With regard to petroleum we have endeavoured to record and to interpret phenomena as we observed them. None can say that the island is devoid of possibilities in this direction.

DISCUSSION.

The Chairman thought the Institution was much indebted to the author for a most valuable contribution to its records. As the author had stated in the opening sentence of his paper, very little information in the English language was available regarding Madagascar, and therefore his contribution was all the more valuable.

The Institution was fortunate in having present at the meeting that evening two members whom it was very seldom they had the pleasure of seeing, and in the name of the Institution he offered a very cordial welcome to Dr. Clapp and Mr. Iaroslavici. Mr. Iaroslavici, who was a member of the Committee of the Rumanian Branch, had unfortunately to leave the meeting at an early hour, but at the same time the members were very pleased indeed to have had his presence at the meeting even for a short time, and they trusted that when he went back to Rumania he would carry with him pleasant recollections of his visit to the Institution and that it would have the result of other Rumanian members attending meetings of the Institution. He had much pleasure in asking Dr. Clapp to open the discussion.

Dr. F. G. Clapp said it was a very great pleasure indeed to him to attend a meeting of the Institution after the lapse of a large number of years. He had derived a great deal of valuable information from the paper, which unfortunately he was incompetent to discuss, not having visited Madagascar. He desired, however, to extend a message of greeting to the members of the Institution from the American Institution of Petroleum Geologists. He was happy to say that some of the members of the English Institution were members of the American Institution, and also to say that the American Institution took a great pride in co-operating with technical societies all over the world dealing with subjects of geology and petroleum. He hoped some of the English members would have an opportunity of visiting the American Institution. Unfortunately, being a traveller, he very seldom had an opportunity of visiting either the English or the American Society, but he hoped that he would be able to attend more of the meetings in the future

than had been the case in the past. He thanked the Chairman for his kind words of welcome.

Mr. Campbell M. Hunter, O.B.E., said that he felt it might interest Dr. Wade to know that in 1910 he had sent out a party to examine the reputed oilfields of that great island. As those who had seen the photographs shown that evening would appreciate, the earlier trip was somewhat of an enterprising character, while his recollections of the account brought home enabled him to confirm all that the author had stated about the appalling transport conditions. Unfortunately, he had not had time to look up his own records of the expedition, as he felt sure the maps, sections and plans might have helped to throw further light on what the author had said. He remembered very distinctly, however, that the conclusion at which he arrived at the time was that the occurrences of oil were closely associated with, if not entirely occasioned by, dykes which intersected the district. The wells that had been drilled up to that time by a French group had failed to disclose the presence of oil in commercial quantity, and he recalled that volcanic ash was encountered in close contact with the oil-bearing beds. While his recollections of the details of the 1910 expedition were, unfortunately, a little clouded in his mind, he was glad to find that the results of Dr. Wade's exploration were so closely in line with his own recollections of what his earlier party had reported.

The Secretary read the following communication from Mr E. H. Cunningham Craig :—

In this paper Dr. Wade has given us a very clear and interesting account of an island about which really definite information has been difficult to obtain. I have never visited Madagascar, but acted for some months as unpaid adviser to one of the unfortunate companies that attempted to develop oilfields in that country, and consequently had through my hands a large number of maps. sections, sketches, and the logs of wells. It seems evident from what Dr. Wade has told us that faults of the " rift " type commenced long before the Great Rift in Africa first commenced to make itself evident. This fact is interesting in connection with the theories of continental drift.

The conclusions that I came to on the evidence submitted to me from Madagascar were that though there were genuine oil-bearing rocks on the island, the formations containing them were of not sufficient depth, and had not been affected by folding movements on a sufficient scale to bring about adequate concentrations of petroleum. Dr. Wade now tells us that towards the Bongolava

folding movements are more pronounced, but even so I fear that there is hardly room for any oilfield of considerable size.

As for the effects of igneous intrusions, there is no doubt that they must have locally distilled oil in many places, and such oil, possibly of quite low specific gravity, may be found along the lines of dykes and other intrusions. Such oil can in almost every case be recognised and distinguished from crude petroleum through its giving chemical evidence of having been cracked, and so resembling many of the oils found included within or associated with igneous intrusions in South Africa, though in the latter case the oils have no doubt been distilled chiefly from carbonaceous rocks, cannels, torbanites, etc. The phenomenon of dykes that do not quite reach the surface is a very interesting one. Many cases of this are to be seen on the Eastern shore of the Island of Arran, and the strata above the dykes are usually somewhat altered and occasionally infiltrated with cementing material, mostly calcareous. One would expect oil shows along such lines of dyke, if the dyke has passed through carbonaceous or oil-bearing rocks at a lower level.

I am afraid that Madagascar, though certainly possessing oil sands over a large extent of country, will never provide us with a working oilfield.

Major T. R. H. Garrett said that four or five years ago he tried to obtain some information in regard to the geology of Madagascar, and he failed, miserably. The members now had, thanks to Dr. Wade's paper, much valuable information in regard to Madagascar placed at their disposal. He desired to ask the author two questions—firstly, What was the distance from the volcanic necks to the seepages of petroleum? and secondly, What was the thickness of the dykes and the distance from those dykes to the seepages of petroleum? He did not know whether any members of the Institution were also Fellows of the Anthropological Institute; certainly he had not seen any of them present at its meetings; but Dr. Wade was in direct conflict with such well-known authorities as Huxley, Deniker, Keane and Duckworth in stating that the negroid element was negligible in Madagascar. Granted that all of the negroid element in Madagascar came into Madagascar as slaves, i.e., that they were imported, the authorities he had quoted, in addition to a recent French authority, thought that that element was appreciable even amongst the Hovas. Amongst the Malagasy it was more and amongst the Sakalavas it was still greater, and these views were based not only on ethnological and linguistical affinities, but also on physical anthopology. Dr. Wade had also referred to the Malays, but he did not really mean Malays. Of course, there has been immigration of Malay people

into Madagascar during historic times, but the Oceanic Monguls, who form the main part of the Hova population, came into Madagascar long before the people that were now known as Malays existed. They should be called proto-Malays, Oceanic Monguls, or Malayans, but not "Malays."

Mr. W. H. Howe said he had been much interested in the paper, the general indication of which seemed to be that the production of petroleum in Madagascar was a failure from a commercial point of view. He had read in the Press during the past few days the report of the meeting of the Mozambique Oil Company, which he presumed was on the mainland. That company had been successful, and he would therefore like to know if the geological formation of the Mozambique Oil Company's lands was similar to those in Madagascar. He desired to raise one other question which had been partly referred to by one of the previous speakers. He would like to know about how far Bemolanza was inland, and would it be possible if oil was obtained, to get it through the Jurassics down to the coast? It lay in a valley, and it seemed to him that tremendous work would be involved in getting it over or through the mountains if the rivers were not navigable, in addition to which it was necessary to get it down to the sea. If oil was obtained, it seemed to him it would be almost impossible to deal with it commercially as the overhead charges might be so enormous.

Dr. Arthur Wade, in reply, said his paper was based chiefly upon his own observations together with reports, written by French geologists and engineers, which were placed at his disposal whilst he was in Madagascar. In reply to Major Garrett's questions, the distance between the main volcanic necks and the seepages was at least four or five miles, while dykes occurred close to the seepages. There is, however, a beautifully preserved but small volcanic vent right in the oil-impregnated area at Bemolanza. At Folakara a dyke ran along the base of the cliff where the seepage occurred. There was also a dyke a few yards away behind the cliff at the top, so that the dykes were on all sides of the seepages. The dyke at the bottom of the cliff was about 8 feet wide; the dyke at the top was not more than 4 feet wide. The dykes varied very greatly in thickness, sometimes being as much as 40 feet across. With regard to the remarks Major Garrett had made on the subject of the negroid element, he had accepted the conclusions arrived at by the two Grandidiers who carried out their investigations in Madagascar in which he believed they had an advantage over some of the authorities mentioned. He was at first strongly inclined to believe that the older ideas were correct, especially with regard

to the Sakalava tribes, but a study of the works referred to in the footnotes, one written as recently as 1920, had caused him to revise his first impressions. The Hovas were, he thought, just as pure Malay as any so-called Malay of the present day, whether from Java or the Malay States. Negroid types had a pretty wide range but that did not necessarily mean that they originated in Africa. What he said was that there was no important African element in Madagascar, which might be quite a different thing. The admixture of slave descendants and Arabs with inhabitants of Indo-Milanesian origin was comparatively small. It was a matter of controvery at the present time as to whether any Bantu element existed in the island. One observer of recent years claimed to have discovered traces of old Bantu settlement in the western parts of the island. Personally he was inclined to accept the two Grandidiers as the most reliable authorities with regard to the ethnology of Madagascar. With regard to Mozambique, it had a structure similar to that noted in Madagascar ; the conditions were almost exactly the same. There was a gneissic plateau and Triassic beds similar in type and character, impregnated in places with oil. Bemolanza was about 80 miles from the sea. Preliminary surveys had been made for a railway, which would connect the area with the coast and supply an outlet for the area. The area between Bemolanza and the coast provided no great engineering difficulties for such a project. There would be no difficulty in transporting the oil to the coast and shipping it away if sufficient production were obtained.

On the motion of the Chairman, a hearty vote of thanks was accorded to Dr. Wade for his interesting and instructive paper, and the meeting terminated.

INSTITUTION OF PETROLEUM TECHNOLOGISTS.

THE ONE HUNDRED AND SIXTEENTH GENERAL MEETING of the Institution of Petroleum Technologists was held at the Royal Society of Arts, John Street, Adelphi, W.C., on Tuesday, January 8th, 1929, Mr. Alfred C. Adams, President, in the Chair.

The Secretary reminded members that nominations for Council should be in his hands not later than January 31st.

The Secretary announced that the following gentlemen had been elected :—

Members.—Roland Llewellyn Hunter ; Henry Norman Short ; Frederik Willem Lodewijk Tydeman ; William Wallace ; Evan Clifford Williams.

Transference to Member.—Robert Louis Charles Bleeck ; Geoffrey Chambers Flower ; Douglas G. Smith.

Associate Members.—Arthur Frederick Castle ; Cuthbert Vincent Rutherford ; Archibald Walker Thompson ; Gerard Anstis Wadham.

Transference to Associate Member.—Philip Ernest Taaffe O'Connor ; Albert Rabson.

Students.—S. Krishnaswamy ; Eric Edwin Manning ; Fatollah Khan Naficy ; Nand Lal Pasi ; George Richardson ; Chaman Lal Wadhera ; Reginald Wilkinson.

Associates.—Archibald Percy Fox ; Alan Warwick Percy.

The President said it was his privilege to introduce the reader of the paper, Mr. W. H. Fordham. The present was the first paper Mr. Fordham had read before the Institution, although a technical paper from his pen was published in the Journal of the Institution for October, 1925, on "Oil Finding by Geophysical Methods." The author had made a special study of the development of that science, and his further contribution would, he was sure, afford the members much instructive and interesting food for thought.

The following paper was then read :—

Geophysical Surveying.

By W. H. FORDHAM, M.A., F.G.S. (Associate Member).

AN attempt is made in the following pages to explain the meaning of the expression "geophysical surveying," and give an idea of the nature and use of geophysical instruments. The value of Geophysics in the search for oil and the cost of surveying are also discussed. A bibliography of representative articles on the subject, to supplement and bring up to date that on pages 468–470 of Vol. 11 of the Journal, has been added.

The writer is fully conscious of the difficulty of dealing in a comprehensible manner with such a wide and obscure subject. His excuse for making the attempt is that he was actually employed on oilfields in Hungary in the early days of the Eötvös Balance, was in touch, at the time, with the work then being carried out under Professor Böckh's direction, watched subsequent development closely and, further, has devoted himself to geophysics for the last four years.

By the expression geophysical surveying is meant the application of physical measurements made, in most cases, on the surface of the earth, to the discovery and mapping of hidden geological structures and mineral deposits.

The measurements are made with sensitive scientific instruments, specially designed for use in the field. These instruments are closely akin to those found in laboratories and observatories, and react to various forces—gravity, magnetism and the like—the local variations of which are connected with the physical properties of the beds at and near the earth's surface.

The effects due to the actual surface beds are calculated and deducted from the observed values, the irregularities due to the structures below being thus obtained. From the nature of these irregularities inferences are drawn as to the subterranean conditions.

The physical properties of particular interest to the present-day geophysicist are, in the order of their importance in oil geology, density elasticity, magnetic susceptibility, electric conductivity and radio-activity.

In theory any subterranean body, which differs in any one of these particulars from the beds with which it is surrounded, can be detected by geophysical measurements.

In practice, owing to the lack of sensitivity of available instruments, difficulty of making accurate observations under field conditions, disturbing factors for which only approximate corrections

[All number references relate to the bibliography which is appended.]

can be made, etc., there are fairly well defined limitations in the actual bodies which can be located, and in the conditions under which they can be found. With increased experience and skill in the application of geophysics, cases in which these methods are successful will naturally tend to become more common.

In regard to oil, at the present day there is barely sufficient difference in physical properties between oil sands, and other porous beds containing oil, and the surrounding formations, to enable the actual oil pools to be detected, and, whatever the future may produce and however hopeful certain lines of research appear, there is, as yet, no recognised technique for directly locating oil.

In several parts of the world, however, oil is found in definite relation to well-defined structures with such marked physical characteristics that they can be detected. Having located and studied the structure, the most favourable place for a test well can be chosen, but only a correctly placed well can decide whether oil is actually present.

The structural features, with which oil is commonly associated and which have been investigated by geophysical methods, are Salt Domes, Anticlines and Faults.

Salt domes have marked physical properties in that salt is light, rigid and slightly diamagnetic, besides being a very bad conductor of electricity. Various methods can therefore be applied in the search for domes.

Anticlines not unfrequently have cores of granite or Palæozoic rock which may be sufficiently heavy and, possibly, also sufficiently magnetic to cause measurable anomalies. In other cases anticlines have limestone or dolomite cores, which cause marked diamagnetic but only slight gravimetric disturbances.

Faults not unfrequently bring heavy and light beds into contact near the surface, and then cause local changes in gravity. In any case they are almost always accompanied by magnetic disturbances. The beds on one side of the fault may differ in elastic properties from those on the other side, and this may enable the Seismic method to be applied.

The Classification of Methods.

Geophysical methods are classified according to the physical property on which the measurements are based as Gravimetric, which depends on density; Seismic, depending on elasticity; Magnetic, depending on magnetic properties; Electric, depending mainly on conductivity; and Radiometric, depending on penetrating rays.

The Gravimetric method is used to locate salt domes, which are lighter than the surrounding formations, bosses of plutonic and other older rocks, which are heavier than the overlying newer sedimentary beds, and faults in which displacement has brought heavy and light formations into contact.

The Seismic method is used to locate salt domes, which are highly elastic bodies, and to find the limits of certain types of formation. It is also applied to find the depth of overburden and for various other purposes.

The Magnetic method has been shown to be applicable for mapping salt beds, which are diamagnetic, anticlines with cores of limestone, which is less magnetic than the overlying beds, and granite bosses and other formations containing traces of iron. It has also been recognised for some time that faults show considerable magnetic disturbances. Though these facts have been known for years, the systematic application of magnetic surveying to oil geology is very modern, and has scarcely passed the experimental stage.

Electric methods are being widely applied in the search for those metallic ores which are good conductors of electricity. It is not clear, however, that these methods have yet been used with success in prospecting for oil. Sands containing oil and salt beds are bad conductors, while water-bearing formations are comparatively good conductors, so there appears to be some scope for the method. It has also been noticed that folded beds conduct better along the strike than across it, and this might made electric surveys useful in certain circumstances.

The Radiometric method can be used to locate formations which emit penetrating rays. Very few field observations have yet been made. There is, however, reason to believe that rays, decidedly more penetrating than the gamma rays of Radium C, are present in appreciable quantities above oil sands in certain fields, and, if this were shown to be a common case, a fairly widely applicable method of locating oil might be developed.

Instruments and their Uses—Gravimetric.

In the gravimetric method the instruments used are the Eötvös Torsion Balance, invented by Baron Roland von Eötvös, forty years ago, and the Gradiometer. The latter was described by Brillouin[6] in 1908, but difficulties of design have only lately been overcome, and the first satisfactory instrument was made in 1927[15].

The Eötvös balance measures four quantities, the two gradients of gravity and the curvature values. The gradiometer measures of the two former only.

For Geological Work gradients are usually considered of far greater importance than curvature values.

The Eötvös Balance consists essentially of two weights on a light beam suspended on a torsion wire. The necessary condition is that the weights should not be in the same horizontal plane or in the same vertical line.

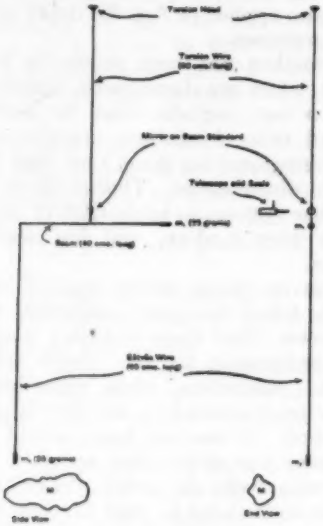


FIG. 1.

The arrangement and approximate dimensions adopted by Eötvös are shown in Fig. 1, one of the weights being fixed to one end of the beam, and the other suspended from the other end on the Eötvös wire.

The instrument does not measure the absolute value of gravity, but certain other quantities, the gradients of gravity, which are the rate of change of the vertical force in two directions at right angles to one another, and the curvature values, of which no simple definition is possible but from which the horizontal directing tendency is calculated.

The mathematics are complicated and are beyond the scope of this paper ; a simple explanation of the reason for the behaviour of the instrument may, however, be attempted. Thus, if there is a heavy body M, somewhere below and to the side of the beam,

as shown in Fig. 1, this body will attract both beam weights according to Newton's inverse square law. The lower weight, being nearer to M, will be attracted more strongly, and the whole suspended system will turn until the twist of the Torsion Wire balances the difference in the couples due to the forces on the two weights. There will also be a tendency for the beam to tilt, but this will not be appreciable.

It is clear that observations with the instrument oriented in several directions will be necessary to enable the direction and size of the force, due to the body M, to be calculated. To reduce the number of "settings" needed at each station, instruments are fitted with two beams, parallel to one another, with the lower weights at opposite ends. It is also obvious that, provided M is at some distance from the instrument, the couple on the beam will obey the inverse cube law, as it is the difference between two inverse square couples.

This inverse cube law is important in geophysics, as it applies to gravimetric, magnetic and electric methods. It means that if a body at a certain depth gives rise to anomalies of a certain size, the same body at twice the depth will give rise to anomalies of only one eighth the size.

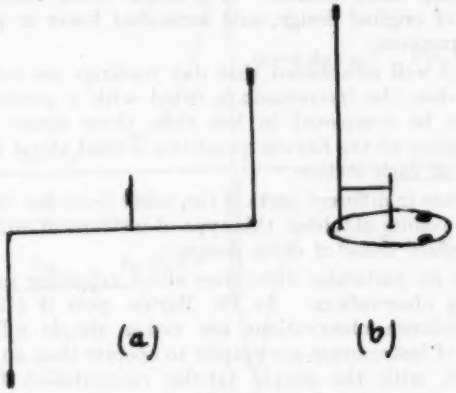


FIG. 2.

New types of rigid beam are shown diagrammatically in Fig. 2, (*a*) being the Z beam of the Askania small balance, designed by Schweydar, and (*b*) a form of gradiometer beam used in the Oertling small balance, designed by Shaw and Lancaster-Jones. The reason for adopting rigid beams is that instruments fitted with

such beams are found to be less affected by disturbing forces, and to give better results by day, than the earlier instruments.

The appearance of standard balances is too well known to need description, and only their general characteristics needs be mentioned.

The large balances made by Suss, Askania, Oertling and the North American Exploration Co. all have Eötvös beams of approximately the dimensions used by Eötvös, are extremely sensitive, work better by night than by day, and need at least seven hours at each station. Observations are usually made automatically.

The price of these instruments is about £1,000.

Of the small balances the visual reading instrument made by Suss[8] is, probably, the most widely used. It is a light, easily portable balance, similar to, but somewhat smaller than the original Suss instrument. It needs five or six hours at each station, and works better by night than by day. In an ordinary survey ten or twelve stations are done on the average each week.

The Askania small balance[1] is a photographically recording instrument which works in a satisfactory manner by day, so that three stations can be completed in 24 hours.

The cost of these two small balances is about £750.

The Oertling small balance[15] is a single beam visual reading instrument of original design, and somewhat lower in price than earlier instruments.

It is fairly well established that day readings are satisfactory, and that, when the instrument is fitted with a gradient beam, stations can be completed in less than three hours. When a beam measuring all the Eötvös quantities is used about four hours are needed at each station.

If experience in different parts of the world bears out the promise of the early results obtained, this type of instrument will certainly tend to displace those of older design.

There are no particular difficulties about adjusting instruments and making observations. As Dr. Barton puts it (12, p. 47): "Torsion balance observations are rather simple affairs. The visual type of instruments are simpler to operate than an explorer's alidade and, with the simple tabular computation forms, the calculations are reduced to a routine of elementary addition, subtraction and multiplication. A bright young man without technical education can be trained to be an efficient torsion balance operator (for the Suss type of balance) more easily than he can be trained to be an efficient plane-table instrument man."

Gravity balance measurements are made in a unit, called the Eötvös, which is 1×10^{-9} C.G.S. units.

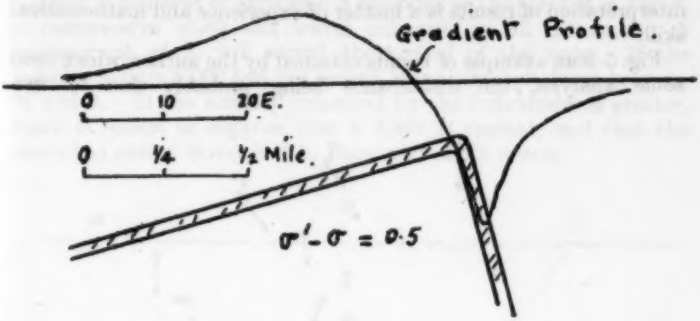


FIG. 3.

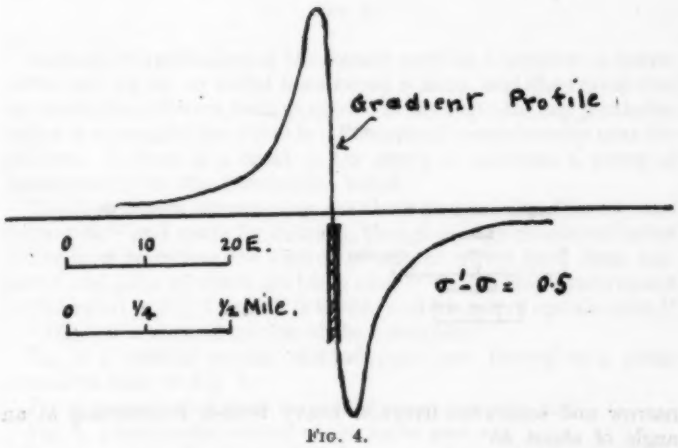


FIG. 4.

The theoretical effects obtained on making traverse surveys across two typical heavy structures are shown in Figs. 3 and 4, Fig. 3 showing the gradient profile due to an unsymmetrical anticline and Fig. 4 the profile due to a vertical dyke.

The actual values obtained in practice are usually much more irregular than these and, except in the very simplest cases, the

interpretation of results is a matter of experience and mathematical skill.

Fig. 5 is an example of results obtained by the author, which need some analysis, the disturbance being probably due to two

Fig. 5.

narrow and somewhat irregular heavy bodies, intersecting at an angle of about 45°.

Seismic.

The seismic method, as applied in salt dome countries, is based on the fact that sound travels through air at about 1,100 feet per second, through ordinary surface formations at about 6,000 feet per second, and through salt domes at 16,000 feet per second.

Thus, if a charge of dynamite is exploded at the point M in Fig. 6, a compressive wave will travel outwards in all directions. A seismograph at S. will record the arrival of the wave. If the velocity is only 6,000 feet per second there is no salt dome between M and S. If the velocity measured by the instrument is greater, there is reason to suppose that a dome is present, and that the wave has passed through it in some part of its course.

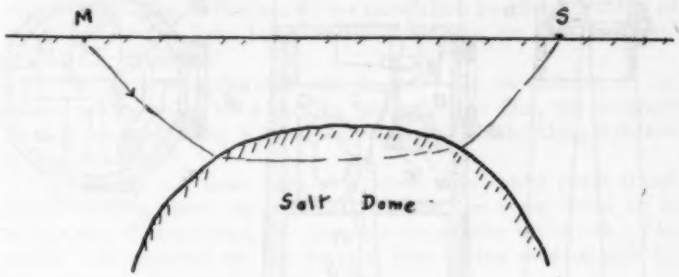


FIG. 6.

In another application of the seismic method a number of instruments are set up on radial lines round a mine, and the travel-time curves on the different radii plotted. If the curve for any particular radius is a straight line there is no structural unconformity near the surface; if there is a break in the curve it indicates a plane of discontinuity in the formations below.

The best known seismometer are those designed by Mintrop and Schweydar[23] and made by Askania, though a large number of other methods of recording the arrival of seismic waves have been suggested and some of which are being used.[20-1-2] Mintrop's instrument is illustrated in Fig. 7, which is taken from his patent specification.[18]

"Fig. 1 is a vertical section of the instrument.

Fig. 2 a vertical section of the upper part thereof in a plane normal to that of Fig. 1.

Fig. 3, a horizontal cross section of the upper part, and

Fig. 4, a horizontal section of the lower part.

In a closed case there is carried, by means of a spring 2, a weight 3. The case is set perpendicularly by means of a level 4. Upon the weight stands, fixed thereto, a light arm 5, having at its upper end a thin spring 6. The latter bears with light pressure, by means of a small friction block 7, against a thin spindle 8 carrying a small mirror 9. The spindle is easily rotatable on points in jewelled bearings; 10 is a converging lens, through which light can fall upon

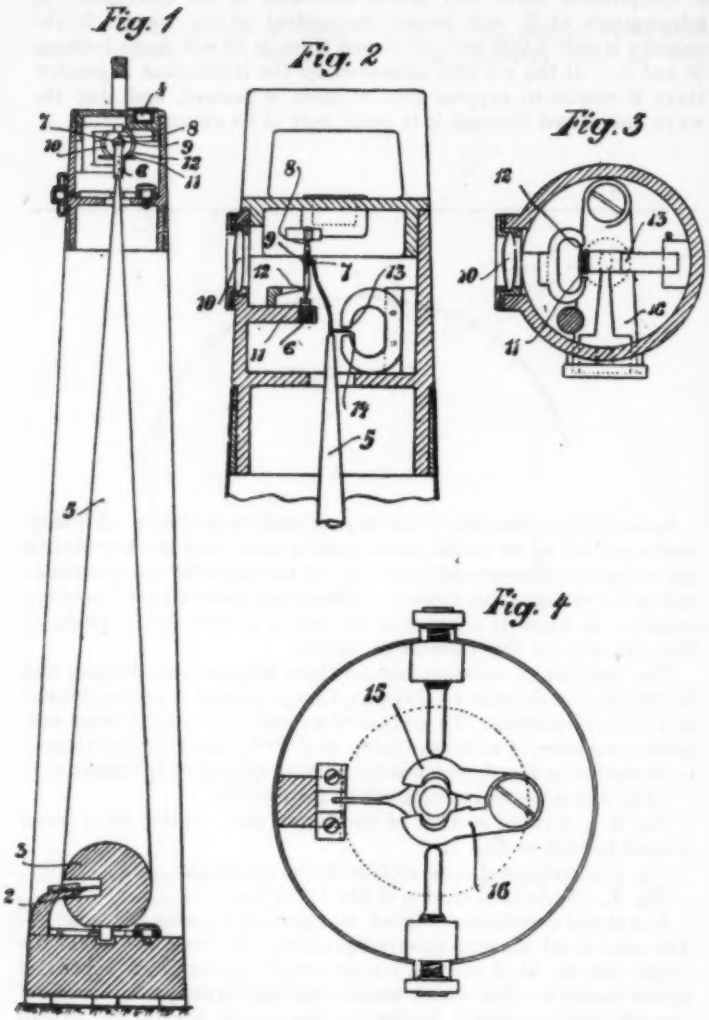


FIG. 7.

the mirror and pass out of the casing again. The spindle 8 has fixed to it an iron pin 11, in the field of a magnet 12. The effect of this arrangement is that the mirror, even after the strongest shock, returns to its normal position. The damping of the oscillations of the weight and arm 5 is effected by a magnet 13, into the field of which a small iron plate 14 extends. For purposes of transport the pendulum is made fast by means of two clips 15 and 16. The whole instrument weighs only a few kilogrames, and can be carried very easily. The oscillations of the mirror can be visually obsr ved by means of the light beam which it reflects, or can be photographically recorded."

In the form of apparatus now in use[19] the oscillations of the mirror are recorded on a moving photographic film, the arrangement illustrated in Fig. 8 being adopted in which the film[22] is driven by clockwork.[21]

To measure the time interval a small short-wave radio transmitter sending Morse signals is placed near the mine, fitted up in such a way that on firing the mine the transmitter is cut out. The signals are recorded on the moving film of the seismograph by means of a radio receiving set.

A seismograph costs between £400 and £500. This does not include the radio equipment.

A survey party consists of three or more groups, each equipped with a seismograph, radio transmitting and receiving sets, apparatus for exploding dynamite charges, etc. Charges are exploded by each group in turn.

The Petrolometer of Dr. Spitz[24] is a third variation of the seismic or sonic method.

The instrument is reported to be on the same principles as the submarine detector, used in the war, and the newer depth finding apparatus used for mapping the ocean bottom. Dr. Spitz apparently asserts that the only formations which do not reflect the sound waves used by him are oil and oil sands, and that this enables oil pools to be directly located.

Magnetic.

As a result of the Magnetic surveys of a number of countries the conclusion was ultimately reached that the local magnetic disturbances noticed were intimately connected with geological structure. Surveying by absolute methods was, however, too tedious for practical purposes, and it was not until sensitive variometers came into being that the application of magnetic methods to geology m e possible.

Shortly before the war Schmidt, of Potsdam Observatory, designed the first satisfactory Vertical Field Balance[2] and the

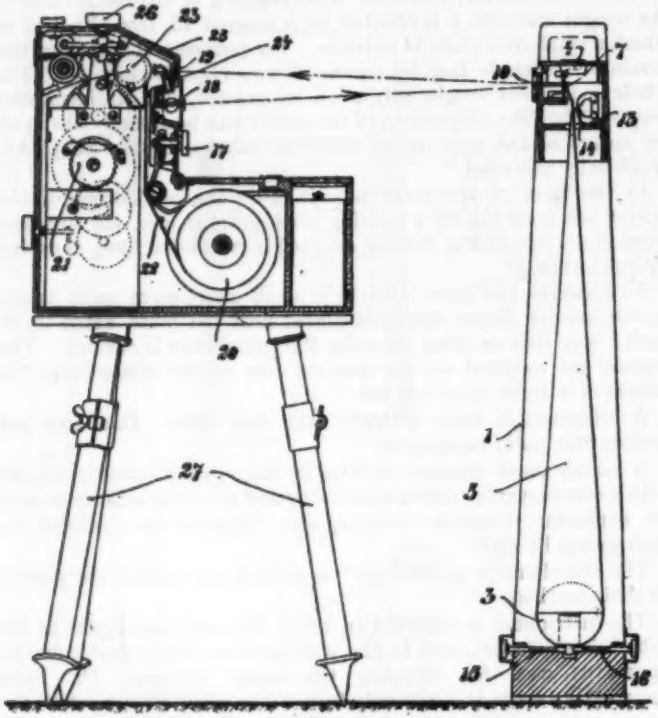


FIG. 8.

late G. W. Walker, of Eskdalemuir, the first Horizontal Magnetometer.[28]

Measurements of the vertical component of the magnetic force have been shown to be of greater value than observations of the horizontal component, in locating geological structures, and Schmidt's magnetometer, made by Askania, has become the standard survey instrument.

This instrument is a portable form of Lloyd's Observatory Vertical Force Magnetometer. The moving part consists of a

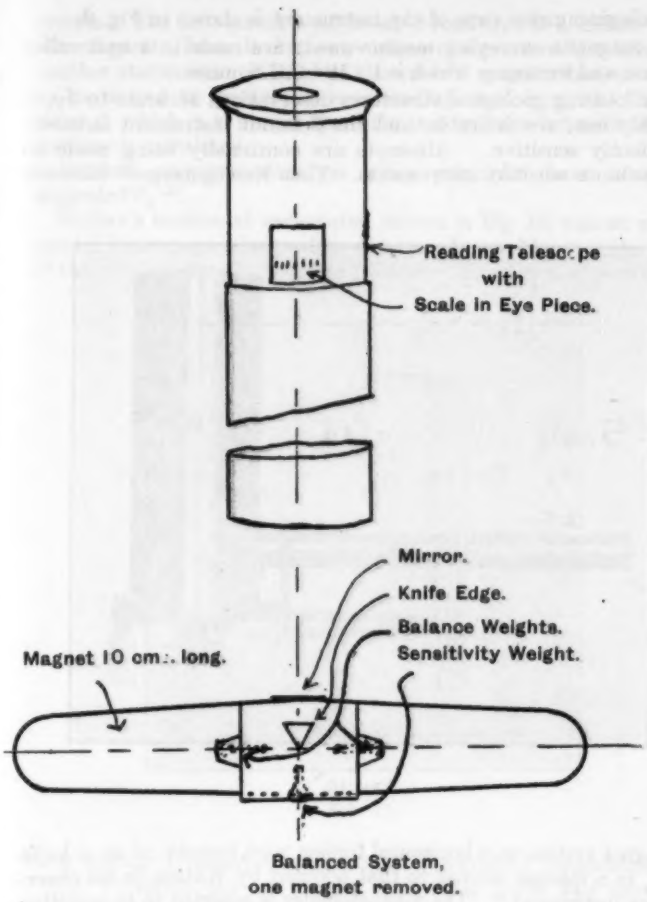


FIG. 9.

centre piece carrying a pair of flat magnets, knife edge, mirror, and balance and sensitivity weights.

When taking observations the instrument is oriented in the East and West direction, to eliminate the effects of the horizontal component, and the knife edge lowered on to agate cylinders. The position of the moving system is read by means of a telescope which has an illuminated scale in the eye piece.

A diagrammatic view of the instrument is shown in Fig. 9.

In magnetic surveying measurements are made in a unit called gamma and written γ. which is 1×10^{-5} C.G.S. units.

For locating geological structures observations accurate to 5γ, or possibly less, are desirable, and the Schmidt instrument is barely sufficiently sensitive. Attempts are continually being made to design more sensitive instruments. Thus Koenigsberger[31] balances

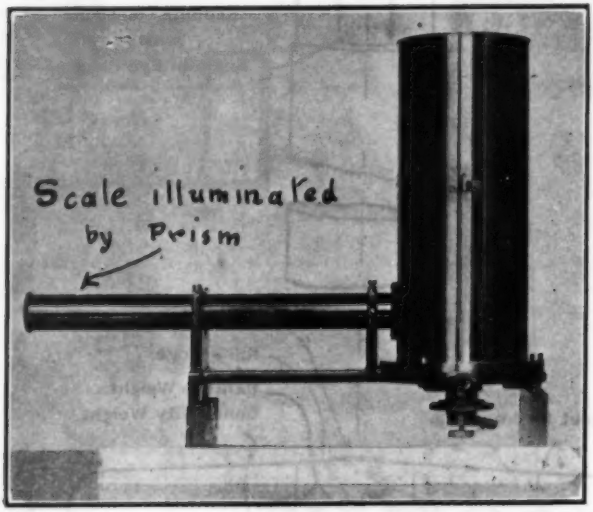


FIG. 10.

a magnet system on a horizontal torsion wire, instead of on a knife edge, in a manner similar to that adopted by Watson in his observatory instrument.[37] The magnetometer is reported to be sensitive and give satisfactory results, but it is not yet widely used.

Oertling has lately brought out a zero reading magnetic balance of the Thomson-Thalen type.[35] The instrument is similar in principle to the Schmidt balance, except that the magnetic force needed to produce a zero reading is measured, instead of the angular deflection of the moving system from the zero position.

The magnetic force is due to a pair of similar control magnets, with poles reversed, carried on racks and pinions below the balanced

system. The instrument is adjusted to read zero at a station where the magnetic force is known; when observations are made at another station one or other of the control magnets has, as a rule, to be moved to produce a zero reading, and from the distance through which it is moved the difference in force between the two stations is calculated.

Vertical magnetometers on other principles have also been suggested[36], [37].

Walker's horizontal variometer, shown in Fig. 10, was an experimental instrument, designed to discover if portable magnetometers of the required sensitivity were feasible. It is a torsion wire instru-

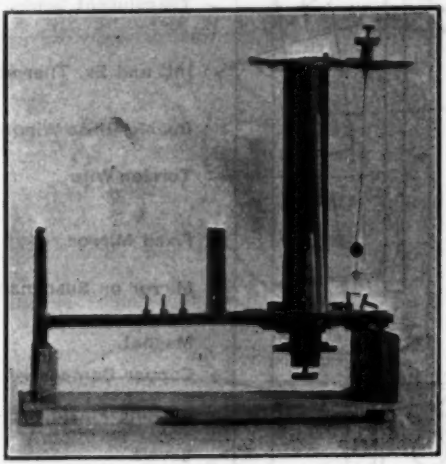


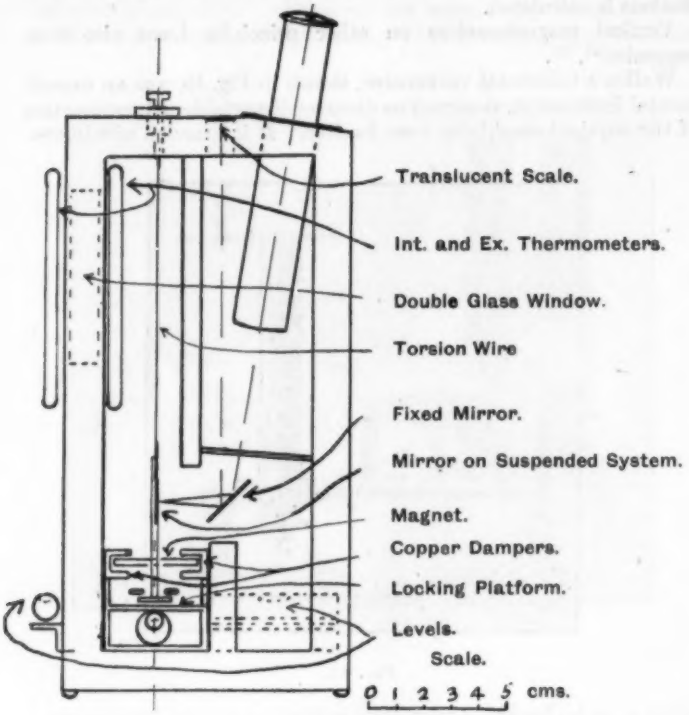
FIG. 11.

ment similar in principle to horizontal observatory magnetometers.

Fig. 11 shows the instrument with outer cover and telescope removed, the suspended system being hung on the right of the inner case. Walker tested it in the Irish Survey of 1915, satisfied himself that observations accurate to 5γ were obtainable, and concluded that an improved instrument on the same lines would prove a success. A more compact type of instrument on the same principle, designed by the author, is shown diagrammatically in Fig. 12.

Some years ago Schmidt designed a horizontal magnetometer in which a vertical magnet system is balanced on knife edges, and

Haalck adopted the same principle in his Universal Magnetometer.[34] There is no means of eliminating the effect of the vertical component and it is doubtful if either of these instruments is proving satisfactory for accurate work. In any case they cannot compete in sensitivity with torsion wire instruments.



WALKER MAGNETOMETER.
(New Design, side of case removed.)
FIG. 12.

Accurate values of the magnetic anomalies are difficult to obtain owing to the diurnal variations of the Earth's field and changes of temperature, for both of which corrections are necessary, and Pautsch has suggested[34] that an electrical device for taking comparative readings at two stations simultaneously is the solution to these difficulties.

In this connection it may be worth recording that Cromwell Varley patented quite a feasible form of Earth Inductor for measuring gradients of magnetism as long ago as 1881.[26]

The cost of magnetometers is about £125.

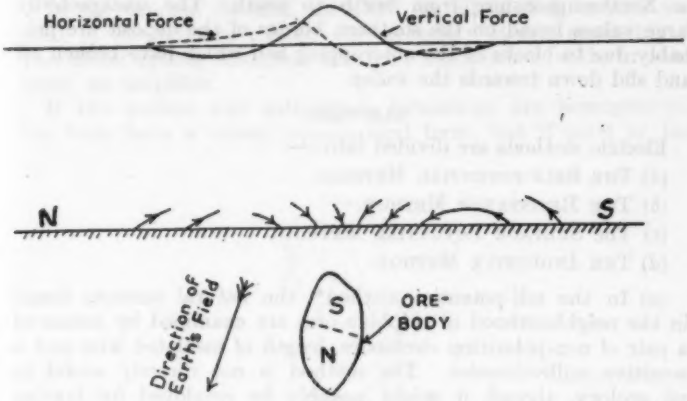


FIG. 13.

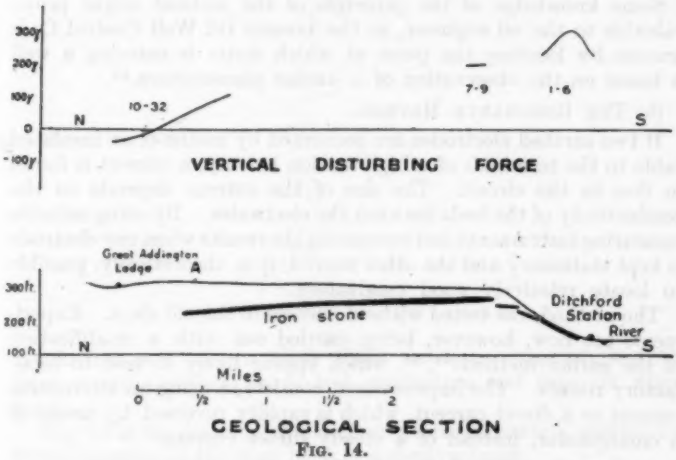


FIG. 14.

To carry out a magnetic survey successfully requires almost as much skill and experience as is necessary for Gravimetric surveying. The interpretation of results is largely a matter of experience.

The theoretical effects obtained on making a North-South traverse survey across a slightly magnetic body are shown diagrammatically in Fig. 13 ; while Fig. 14 gives the vertical profile obtained by the author[35] on crossing the Irthlinborough Iron Ore beds in Northamptonshire from north to south. The unexpectedly large values found on the southern border of the deposit are probably due to blocks of the outcropping bed which have broken off and slid down towards the valley.

ELECTRIC.

Electric methods are divided into :—

(*a*) The Self-potential Method.

(*b*) The Resistance Method.

(*c*) The Surface Potential Method.

(*d*) The Inductive Method.

(*a*) In the self-potential method[40] the natural currents found in the neighbourhood of sulphide ores are examined by means of a pair of non-polarizing electrodes, length of insulated wire and a sensitive millivoltmeter. The method is not directly useful in oil geology, though it might possibly be employed for tracing the outcrop of a bed containing disseminated pyrites.

Some knowledge of the principle of the method might prove valuable to the oil engineer, as the Loomis Oil Well Control Co.'s process for locating the point at which water is entering a well is based on the observation of a similar phenomenon.[44]

(*b*) The Resistance Method.

If two earthed electrodes are connected by means of an insulated cable to the terminals of a high-tension battery, a current is found to flow in the circuit. The size of the current depends on the conductivity of the beds between the electrodes. By using suitable measuring instruments and comparing the results when one electrode is kept stationary and the other moved, it is, theoretically, possible to locate relatively good conductors.

The method was tested without success in the old days. Experiments are now, however, being carried out with a modification of the earlier methods[46], [48], which appear likely to lead to satisfactory results. The improvement consists in using an alternating current or a direct current, which is rapidly reversed by means of a commutator, instead of a steady direct current.

(*c*) The Surface Potential Method.

In this classic method earthed electrodes are connected to a source of electric energy, and the current distribution on the surface mapped by means of equipotential lines.

In the Schlumberger method[40] a direct current, at a voltage of about 100, is used in the primary circuit, while the secondary searching circuit consists of a pair of non-polarizing electrodes, insulated wire, galvanometer and voltmeter.

In the original Swedish method[41] an alternating current was used in the primary circuit, the secondary circuit consisting of two metal spikes, insulated wire and headphones, with, in some cases, an amplifier.

If the surface and sub-surface formations are homogeneous, the lines have a known symmetrical form, but if good or bad

FIG. 15.

conductors are present their shape becomes irregular, and the lines crowd together above bad conductors and separate above good.

Fig. 15 is an example of a surface potential survey, carried out by the author, on the East bank of a shallow lough.

It was thought possible that an ore body might be found, at a small depth, rather to the South West of electrode A, and the survey results appear to show that a considerable conducting body actually exists in the lough at the place anticipated.

(*d*) INDUCTIVE METHOD.

In the inductive method an alternating or oscillating current is passed through a transmitting circuit, which consists, in the Elbof[1] and new Swedish methods,[43] of two earthed electrodes connected to the transmitter with insulated wire, and in other methods (Conklin,[39] Mason,[4] Bieler,[45] etc.) of a loop aerial. An oscillating magnetic field is thus produced in the neighbourhood of the transmitting circuit. This magnetic field is examined with a receiving set consisting of a frame aerial, amplifier and headphones, or some more complicated measuring device. Good or bad conductors cause distortion of the normal field. The Elbof receiving set[42] is shown in Fig. 16, and " comprises a ring 1, which can be turned about both the horizontal and vertical axis, a stand 2, on which the ring is mounted, an amplifier 3, an accumulator 4 for supplying current to the valves, a telephone receiver 5, and if desired, a mirror or oscillating galvanometer 6 for measuring the density of the electric lines of force.

The ring comprises a wooden frame 1, provided on its periphery with a groove on which a great number of windings of very fine copper wire are accommodated. At about half the height of the wooden frame is mounted a clinometer 8 comprising a plumb bob and a quadrant indicating the inclination of the plane of the ring. A compass 9 is provided at the lowest point of the ring in order to be able to determine the position of the plane of the ring with respect to the north-south direction. 10 are terminals by means of which the ring can be connected to the telephone."

This receiving set is used with a transmitting set of the " usual " type.

The arrangement shown in Fig. 16 is top heavy, and in the newer sets the ring aerial is pivoted about a horizontal diameter *d*, in a rectangular frame which can itself be turned about the vertical axis.

A simple wireless circuit for the receiving set is shown in Fig. 17.

In applying the inductive method observations are made with the receiving set at regular intervals along a series of traverse lines near the transmitter.

The position of the frame aerial for maximum and, as a rule, for minimum, reception is noted at each observation point.

Near conducting bodies the position of maximum reception is abnormal, the divergence becoming a maximum, more or less above the disturbing body.

Any skilled wireless operator can design and make satisfactory electric apparatus.

The actual cost of a transmitting set, with petrol driven generator, should not exceed £100, while the receiving sets can be made for less than £25 each.

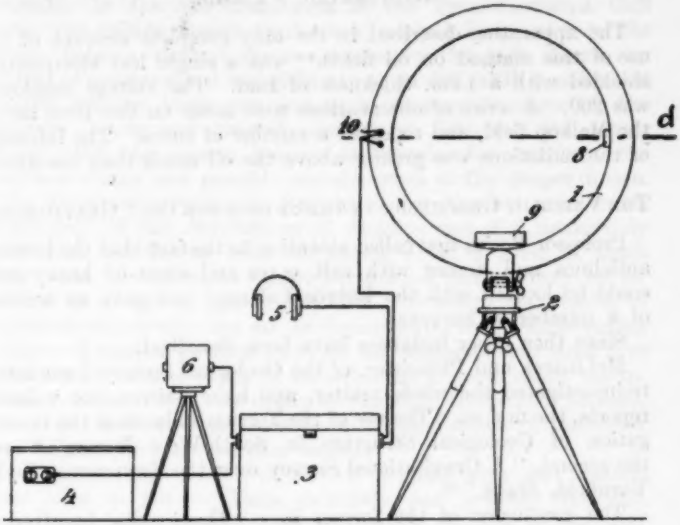


FIG. 16.

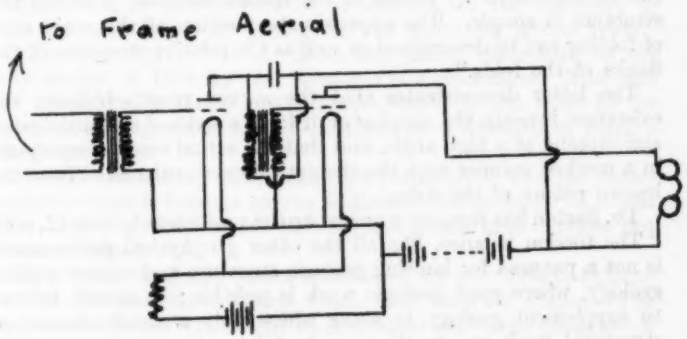


FIG. 17.

Though making electric observations and carrying out surveys does not possess any particular difficulties, the interpretation of results is a matter of considerable uncertainty, and it is only when

the geology of a district is well known that anything more than a tentative explanation can be attempted.

Radiometric Method.

The apparatus, described in the only complete account of the use of this method on oil fields,[49] was a single leaf electroscope shielded with a 1 cm. thickness of lead. The voltage employed was 200. A series of observations were made on two lines across the Maikop field, and repeated a number of times. The intensity of the radiations was greater above the oil sands than elsewhere.

The Value of Geophysics in the Search for Oil: Gravimetric.

Professor Böckh first called attention to the fact that the brachy-anticlines and domes with salt cores and cores of heavy rock could be located with the Eötvös Balance,[7] and gave an account of a number of surveys.

Since then other instances have been described.

McLintock and Phemister, of the Geological Survey, have lately re-investigated the whole matter, and have written two valuable reports, the first on "The use of the Torsion Balance in the investigation of Geological Structure in South-West Persia,"[10] and the second, "A Gravitational Survey over the Swynnerton Dyke, Yarnfield, Staffs."[11]

The conclusion of the former is:—"The results described in the foregoing pages show that the general structure of an area can be elucidated by means of the torsion balance, provided the structure is simple. The approximate position of the main axes of folding can be determined as well as the relative steepness of the flanks of the folds."

The latter demonstrates that the survey results indicate the existence, beneath the capping of drift, of a dyke of the anticipated size dipping at a high angle, and that the actual results correspond in a marked manner with the theoretical curve calculated from the known nature of the dyke.

Dr. Barton has recently summed up the position as follows 12, p. 46 "The torsion balance, like all the other geophysical instruments, is not a panacea for hunting geologic structure and cannot replace geology, where good geologic work is possible; it should be used to supplement geology, in areas where only a small amount of structural work can be done, or to fill in the structure in areas where no structural work is possible. . . .

"The method will give the most brilliant results where it is used in mapping structures that have produced considerable and sharp contrasts in density—for example, salt domes, granite ridges, faults

in which massive limestone or anhydrite are faulted against sands and clays. . . .

"In many cases it is preferable to combine several geophysical methods. In the salt dome area of the Texas-Louisiana Gulf Coast, the mirage elastic earth-wave method is superior to the torsion balance method for reconnaissance for salt domes, on account of greater speed and ability to cover difficultly leasable and passable acreage, lower cost and equal accuracy in detecting the shallower domes and greater accuracy in detecting the deeper domes; but the torsion balance is superior for detailing the shallower domes and possibly certain types of the deeper domes. If the structural deformation is slight or if it does not cause much deformation of the distribution of density, and if a moderately thick hard bed lies at moderate depth under a cover of much softer beds, the reflection elastic earth-wave method may be far superior in accuracy, speed, and cost. Although the results of magnetometer surveys can not be depended on to the same extent as those of torsion balance surveys, the magnetometer does give indication of certain types of structure in a great many places, and as it is faster and less costly to run than the torsion balance, it can be used advantageously on reconnaissance to discover areas to test with the torsion balance."

In regard to the results of torsion balance work Dr. Barton writes (*ibid. p.* 29):—"Three definitely, and possibly five, salt domes have been discovered by the torsion balance in the Gulf Coast salt dome district of south-east Texas and south-west Louisiana within the three years, 1924-26, in contrast to the discovery of only five new domes by geology in the preceding fifteen years.

"The first . . . was the Nash salt dome, discovered in the early spring of 1924 by the Rycade Oil Corporation. This had been considered a faintly suspicious prospect; it was rated by the writer as having about five chances out of a hundred of being a salt dome. . . .

"It was blocked by the Rycade Oil Corporation, and the reconnaissance torsion balance survey indicated the presence of a salt dome with a probability of better than ninety-nine chances out of one hundred. . . .

"The other four salt domes discovered by the torsion balance are the Clemens, Allen, Long Point, and Fannett domes. The Clemens dome was discovered at a locality where the presence of a dome was not suspected. The Allen dome, like the Nash dome, was at a locality where there were some very faint indications of the possible presence of a salt dome. . . . The first indication of the Long Point salt dome was picked up by a German torsion balance crew working for the Gulf Production Co., but the seismograph

more commonly gets the credit for the discovery of the dome, because it was used actually to establish the presence of the dome definitely. . . .

"The Fannett salt dome was discovered by a Roxana Petroleum Corporation torsion balance crew and a German seismograph crew working for the Gulf Production Co., almost at the same time. . . .

"A small oil field has been developed on the Nash dome and a sulfur deposit has been found that is slightly too deep to be mined profitably at present. The Long Point dome has given evidence of being a first-class sulfur dome. . . .

"Two oil wells have been completed on the Allen dome and a small amount of oil has been found on the Fannett dome.

"Some eight or ten torsion balance prospects in the Gulf Coast have been drilled and condemned. In no one of the cases known to the writer did the torsion balance indicate the presence of a dome with a probability of better than twenty chances out of one hundred."

(*Ibid*, p. 33): "The out and out failures of the torsion balance in the Gulf Coast area have been due, in the first place, to inexperience in interpretation; in the second place, to over-optimism in the use of indistinct indications; and in the third place, to the necessity of testing prospects of a lower order of favourability, in the absence of prospects of a high order of favorability."

(*Ibid*, p. 35) "The faults in the Somerset-Luling-Mexia-Powell-Sulphur River zone of faulting can be mapped with the torsion balance. Torsion balance profiles run under the writer's direction across the Sulphur River-Campbell fault, the Quinlan fault, the Powell, Richland, Currie, Wortham, Mexia, Luling faultline oilfields, and faults south-west of Seguin in Guadalupe County and in southern Bexar County, indicated the presence and approximate position of the fault."

(*Ibid*, p. 37) "The work of the torsion balance in the Mid-continent district proper has been mostly reconnaissance to investigate the possibilities of the instrument and as yet very little drilling has been done on torsion balance structures. Although the torsion balance as yet has no Mid-continent oil field to its credit as an outright discovery, the work with the torsion balance in that area shows that it has very great possibilities. Buried granite, gneiss and Cambro-Ordovician ridges such as those in the Panhandle, as the Hambro-Nocona-Bulcher-Muenster ridge, Healdton the Criner Hills, and some of the Kansas granite ridges, show up brilliantly in torsion balance surveys."

(*Ibid*, p. 45) "The results of the very extensive torsion balance work in Mexico by several different oil companies are known only vaguely to the writer. The El Aguila Co. has been using torsion

balances for four years in detailing the salt domes of the Isthmus of Tehuantepec. Several accounts have come through of exact verification by the drill of predictions made from torsion balance results in regard to the flanks of the salt core. . . . In the Panuco district, the torsion balance is said to have shown that a trend of production which unexplainably lay at an angle to the strike of the surface structure coincided with the crest of a buried ridge in the basement complex. A brilliant piece of work is reported in the location of faults in the Panuco district."

Seismic.

In the discussion on the papers on Geophysical Prospecting presented at the New York Meeting of the American Institute of Mining and Metallurgical Engineers in February, 1928, Mr. DeGolyer said (5, p. 12): "I am sorry we have no paper on the seismic or sonic method, but I suspect the thing is so mixed up with the patent situation that it is rather difficult to get a good paper. The seismic or sonic method practically replaced the torsion balance, which was first in the field, as an instrument to be used in the reconnaissance of wide areas for salt domes. Much more ground can be covered and it can be covered more rapidly."

Dave P. Carlton in his evidence to the U.S.A. Radio Commission last year stated[25]:—

"In the last three years seismology in Texas, Louisiana and Mississippi has been the means of discovering at least thirty salt domes, a type of structure with which petroleum and sulphur are associated in that territory . . ."

"The use of seismic methods in geophysics has only just begun. It has already proved itself a much more economical method of locating domes than the drilling of wells."

Magnetic.

There is a mass of evidence due to Walker,[29] Schuh,[30] Krahmann,[2] Meyer[32], Jung and Geoffroy[33] and others, which shows that subterranean features of various types give rise to decided magnetic anomalies, that can be mapped with modern instruments. Of the use of magnetometers in oil geology little has been published. L. Spraragen has, however, lately made a number of magnetic investigations in the United States and reports as follows[38] (p. 38):—

"Of all geophysical devices now employed in the exploration for new oil-producing structures, the magnetometer is perhaps the most extensively used. It lends itself very readily to field use and can be operated as a single unit by anyone with an average amount of intelligence. With it, the areas to be investigated can be covered

very rapidly and at a total cost not to exceed a fraction of a cent per acre.

" The magnetometer has been used in Alaska, Canada, California, Texas and the Mid-Continent area.

" In many instances in West Texas where the magnetometer has been used to check over known fields the magnetic anomalies correspond very closely with geological structures. In Kern County, California, the magnetometers give a very surprising picture. Magnetic reliefs of 700 γ in a distance of two miles have been found and though in general the actual magnetic highs are somewhat displaced from the actual known structural highs, yet it is possible by means of the simplest application of the principles governing magnetic fields to pick out the most favourable areas.

" In parts of Oklahoma, particularly in Kay, Grant, Garfield, Noble, Kingfisher and Logan Counties, the magnetometer survey presents a picture which is apparently quite different from the known geological facts. It is possible, however, that with a careful analysis, the magnetometer work in this area can be interpreted.

" Of course, in the above mentioned counties in Oklahoma the granite is very deeply buried and naturally the effects produced on the magnetometer will be quite weak. For this reason it is necessary when working in an area of this nature that the magnetometer survey should be done with extreme care and the limits of error closely watched. In one particular instance in northern Oklahoma where a survey was made and contoured on a 25 γ interval the important points were not brought out, but when the work was repeated and contoured on a 10 γ interval these important details were clearly shown.

" In the Panhandle area of Texas, particularly Dallam, Sherman, Hansford, Hartley, Moore, Hutchinson and Wheeler counties, the magnetometer results are almost identical with the geological structure. The same is true in Foard, Wilbarger and Wichita counties."

Spraragen concludes that the ideal application of the magnetometer survey is to determine areas favourable for core drilling.

Electric.

Of the employment of electric surveying in oil geology very little of a convincing nature has been written.

The Schlumberger method[47] was used in Rumania in 1923, and the results obtained over the Boldescii anticline are considered to have corresponded fairly well with the actual structure.

Two salt domes were discovered in Alsace, by the same method, a few years ago. The results, in this case at any rate, could no doubt have been obtained more cheaply by some other geophysical method.

The Sundberg inductive method was employed in the Vienna basin in 1926[43] to find the depth of the salt water horizon at a number of points. Two dome structures are supposed to have been located at Schwadorf and Lanzendorf respectively.

The Elbof method[1] is reported to have been used in various investigations on oil and gas fields, with success. It is claimed that oil and gas deposits are such bad conductors of electricity that they can be directly located.

The Cost of Surveying.

Dr. Barton reports[5] (p. 11): "In all Mr. DeGolyer's work of which I had charge, it cost us, including depreciation and everything, $1000 to $1200 a month per single torsion balance. That is based on two stations per day.

"The standard consultant rates run about $5500 a month with a two-instrument party (*ibid*, p. 14). I have understood that ordinarily it figures 4 to 8 c. per acre with the seismograph and 15 c. with the torsion balance for reconnaissance for salt domes. . . ."

"For detail work with the torsion balance, for a standard-size dome with a diameter of about 1 mile, about sixty stations will be necessary; that is, about six weeks' work. The cost would be $2000 to $4500 for about 1500 acres."

Spraragen calculates that the cost of magnetic surveying[38] is rather less than one dollar per station, if the stations are some distance apart. For detailed work the cost would be somewhat less.

For reconnaissance surveys the cost is about 0·2 cents per acre.

Max Mason[4] calculates the cost of electric surveys as between $5 and $7·50 per acre.

In this connection the estimate for the Australian Experimental Geophysical Survey[3] is worth consideration.

The object of the survey is to ensure a large-scale trial of electric, gravimetric and magnetic methods individually and in combination, with full publication of the scientific information and experience acquired.

A complete set of electrical apparatus, and sufficient gravimetric and magnetic instruments for a two-instrument party of each, have been acquired, the whole outfit including motors, surveying instruments, camp kit, etc., being estimated at £4000.

The salaries, wages, field allowances, contingencies and renewals for two years were originally calculated at £21,400, this figure being later increased by £5,000.

The survey personnel consists of a survey leader, a physicist to direct the gravimetric and magnetic work, an electrical specialist to carry out the electric surveying, a physics laboratory assistant, two surveyors, four labourers, a cook and "assistants."

To enable full electric, gravimetric and magnetic parties to be constituted the assistants will, presumably, gradually be increased to ten or twelve, and when that has been done, and the observers have become familiar with the instruments a large amount of surveying should be accomplished, 20 balance stations, 200 magnetometer stations, and possibly 100 acres of detailed electrical work being done per week, at a cost not far removed from American figures.

Conclusion.

From the results described in the present paper it is evident that geophysical methods are already proving a valuable aid to the geologist; and it is reasonable to look forward to a time when the subject will be an important branch of geology.

The limitations both of the methods and of interpreters are becoming better understood, at any rate in the United States.

On the question of interpretation, which, after all, is the most vital part of geophysics, Dr. Barton (*ibid*, p. 48) has expressed himself in the following notable manner, and his remarks apply to other geophysical methods in addition to the gravimetric which he specifically mentions: –

"To get the most out of torsion balance surveys, the interpreter should be a good mathematician and geologist, should have had a chance to study the mathematics of interpretation and should have had a broad practical experience with the method. There are very few men who have had sufficient opportunity to study the mathematics of the interpretation and who have had sufficiently broad experience to qualify as competent interpreters. It is and will be easy to get men who are able and competent observers and who possess a fair but superficial knowledge of interpretation. A great danger to the full realization of the possibilities of the method is that the company employing such a man as an interpreter may fail to recognize his limitations. Another danger is that a company that realizes the necessity of training itself and its interpreter by theoretical study and practical experience will become over-impatient and over-enthusiastic and may force him to practical utilisation of the method before he is competent to use it. A company that has had much experience with geology has become educated to

the fact that geology is not a "sure-shot" panacea for finding oil, and is satisfied to allow geology a considerable number of failures if it turns up a fair number of successes; but there is a good possibility that the same company will condemn the torsion balance after a very few failures, without regard to whether the failures were due to the method or to the incompetence or inexperience of the interpreter."

One may perhaps sum up the position in the following manner: Geophysics have been applied with success to certain geological problems, and are likely to be used more widely in the future.

The principle of field instruments is beginning to be understood, and instruments for particular purposes can be designed and made.

Standard instruments, the behaviour of which is known, now exist.

Intelligent individuals, who need not possess special mechanical or scientific ability, can be trained in a few months to become competent observers.

There is, however, a serious deficiency of geologists capable of acting as survey leaders and interpreters; for stress must be laid on the fact that applied geophysics is a branch of geology and that, speaking somewhat generally, only those trained from childhood as geologists are likely to become successful interpreters. It is for the physicist to devise methods, design instruments and evolve formulæ, but the field work must be in the hands of the geologist.

A second obstacle to the wider application of geophysics is the lack of knowledge of results already obtained. It is noticeable, especially in official investigations, how often experimental surveys of the same tectonic features are repeated.

How the deficiency of interpreters can be made good is a matter for serious consideration and which only time can overcome.

To remove the second obstacle the Geophysical Institute, which the late Dr. Chree advocated six years ago, is almost essential.

Such a body would follow and keep a record of the work taking place throughout the world and, by ensuring the necessary liaison between physicists, instrument makers and geologists, would greatly facilitate the development of geophysical methods on sound lines.

Bibliography.

Note.—The libraries at which these publications may be consulted are indicated by the letters in parentheses: G., Geological Survey; I., Institution of Petroleum Technologists; P., Patent Office; S., Science Museum. The numbers refer to Abstracts which have appeared in the Journal of the Institution of Petroleum Technologists.

General.

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[7] "Der Nachweis von Brachyantiklinalen und Domen mittelst der Drehwage." Dr. Hugo von Böckh. *Petroleum Zeitschrift*, 1917, 12, No. 16. (P.)

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[43] "Uber die jüngsten Erdolforschungen in Wiener Becken." Karl Friedl, *Petroleum Zeitschrift*, 1927, **6**, 23. (I., P., xiv., 599.)

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DISCUSSION.

The President said he was sure the members would desire to congratulate the author on a very instructive and interesting paper which, it seemed to him, was a remarkable effort to add to the general information on what was a very important subject, and he hoped that the geologists present would be able to deal with the subject which the author had explained.

Mr. W. R. MacDonald said the main difficulty in geophysics at the present time, setting aside, of course, the technical features the limits of which were now much better understood, was its application to specific cases. The author had voiced that difficulty very ably when he stated that a geologist must be the leader of any expedition. He had had a considerable experience of geophysics, and had collaborated with many eminent scientists in the execution of his duties; and with that experience in mind he desired again to emphasise the importance of having a suitably selected geological area where the different geophysical methods could each be expected to function. There were certain areas

throughout the world and in England where known suitable geological conditions occurred, and to which the science of geophysics could be readily applied. The application of geophysics to any particular area abroad usually involved considerable expenditure of money, unless it was well developed by drilling or geological framing. Any new area where likely economic deposits existed required a thorough geological framing, together with a knowledge of specific gravities, conductivities, elasticities and densities, before complete interpretation of any geophysical survey was possible. It was these problems, namely, the supply of data, which caused the greatest difficulty, and it was hardly possible to expect individual geologists employed on a survey to provide it. An institution such as had been suggested by the author, in which all such things could be tested out, such as samples, experiments and instruments, would, he felt sure, be of the greatest assistance.

Prof. S. J. Truscott said in his opinion there could be no doubt at all that geophysical prospecting had come to stay. Geophysical prospecting was in essence instrumental prospecting as distinct from the ordinary prospecting of traverse and searching. Being instrumental in character it depended entirely on the advance made in the construction of instruments, and that advance had been extraordinarily rapid within the last twenty years or so. Actually geophysical prospecting started with the dipping needle with which a Scandinavian first of all discovered iron ore deposits. That dipping needle, compared with the elaborate magnetometers available at the present time, was a very crude instrument indeed, but it served the very useful purpose of mapping out the magnetite deposits in Scandinavia. Magnetite had strong magnetic properties, and it was not to be wondered at that a crude instrument discovered it. Since then magnetometers had been so developed that they distinguished the presence of a salt dome even in an ordinary sedimentary environment. An ordinary sedimentary rock had just a small quantity of iron; a salt dome had none; and present-day variometers were so delicate that they could detect that small difference. That was a tremendous advance. The same remarks applied also to the Eötvös Balance, which was almost too delicate for use in the discovery of mineral deposits because they were very largely in terrain of a high relief, for which a complicated series of corrections is required before it becomes possible to disclose the definite conditions underground. He congratulated those seeking petroleum that they had at their command the Eötvös and the Seismic apparatus, which were a very great advance on previous methods that had been employed.

Fortunately they could be used in conjunction with one another. If the results interpreted by the Eötvös Balance were not clear, the Seismic method could be used to supplement them. The electric methods were more suitable for prospecting for mineral deposits. In the ground spontaneous currents sometimes occurred in the neighbourhood of mineral deposits, which were of value for detailed examination of small localities. For examining wider areas independently generated currents must be applied and use be made either of conductivity or electro-magnetic methods, from which good results were possible, and it was to those methods that it was necessary to look for progress in the future. The important point at the moment was to direct greater attention to geophysical prospecting in order that men might be trained to undertake the work. The great difficulty in training such men had been that the instruments were not made in Great Britain but abroad. It was possible now to get instruments made in Great Britain, but even that was not sufficient: it was necessary to train the personnel on a particular and known terrain. In Germany men were trained on a piece of ground which had been explored with regard to its density, its elasticity and so on. He hoped that some public body would take up this question in Great Britain in order that the present disability from which we suffered might be removed.

Mr. H. B. Bateman said there were a few points in the paper to which he would like to refer. It was stated regarding the electrical method of investigation that "it is not clear that these methods have yet been used with success in prospecting for oil." It would be realised that one of the great difficulties in the way of a wider knowledge of the application of electrical methods in oilfields was the fact that the companies for whom work was carried out required that complete secrecy should be observed regarding the work itself and the subsequent confirmation of the results by drilling. He understood that in small, closely packed areas owned by different companies information as to the trend of the oil zone in one area might be taken advantage of by the adjoining owner. As a result of research and field work the Elbof Company had developed a technique which was giving satisfactory results under suitable conditions. During the last four years surveys had been made in Texas, Poland, Rumania and elsewhere; in one case in Texas the company concerned put down seven wells on the zones which were indicated as bad conductors by the electrical method, and they also drilled seven outside of those indications. All the first seven wells reached oil, but in the latter case all the holes were dry, and were subsequently abandoned.

The statement that the inverse-cube law applied to gravimetric, magnetic and electrical methods was perhaps a little misleading. That was, of course, the case with gravitational and magnetic forces, the strength of which could not be controlled in any way by the observer, but in the case of the electrical methods of investigation observations were made as a result of certain electrical forces impressed into the ground and under the control of the observer. For observations at depth not only the strength of those forces, but the conditions under which the observations were made could be modified, and consequently the difficulties entailed in making observations at considerable depths were less marked.

With regard to magnetic work, corrections due to diurnal variations were made from observations taken automatically by a control instrument situated on the field where the work was being carried out. The instrument employed had photographic registration; consequently it only required attention just before the field observations were started and at the conclusion of the day's work.

In the application of the inductive method, he would point out that observations were not necessarily made near the transmitter. In the case of conductors lying at depth, variations were made in the frequency of the alternating current employed, and observations were made with the frame aerial at considerable distances from the transmitting loop, sometimes up to as much as three kilometres. He thought it was open to question whether the design of satisfactory electrical apparatus was quite so easy as the author stated. In radio work the tuning of the amplifier was for a very high frequency, whereas in geo-electrical work the frequency employed was normally from 1,000 to 500 or less. Furthermore, the figures given for cost were very much lower than he had found to be the case.

In the last paragraph of the section dealing with electrical methods there was a reference to uncertainty of interpretation. A study of the geology of the area under investigation was surely an essential factor in all geophysical work. In the magnetic method the author laid stress on the importance of experience in interpreting the results, and the same applied, though perhaps even more strongly, in geo-electrical work.

In reference to the radio-active method : that had been employed in the location of faults and lodes provided cover was limited to some 20 or 30 metres. Research work was in progress in relation to its applicability to oil and oil structure.

There was a reference to oil at the Fannett dome. The areas where that drilling was carried out were previously located by the

electrical method, and the drilling confirmed the results obtained by the geophysical survey.

In Dr. Barton's reference to certain failures with the torsion balance in the Gulf Coast area, there was a note of warning. There had recently been brought to his notice the case of some work in Italy in which an examination of the data showed conclusively that a serious error in the interpretation had been made. In that connection it was no doubt true that the actual practice of the field work could be acquired by an intelligent engineer in a few months, but the experience necessary to ensure accurate and full interpretation was a matter of some years and a large number of investigations.

D. P. Carlton was quoted as saying that the seismic methods had only just begun, but he (Mr. Bateman) understood that investigations of that type were started over four years ago in the Gulf Coast field. In the paragraphs dealing with the cost of geophysical work there was one point in the reference to the Australian survey which might escape notice—he referred to the employment of methods in combination. It was the experience of those who had used all the recognised methods that in many cases a complete investigation was not possible by the employment of one method only. For example, in some recent seismic work carried out over a salt dome, it was found that the salt dome was, on one side, surrounded by a considerable width of Triassic formation in which no oil could occur. That showed that the field for the electrical work would have to be located in quite a different position from that originally anticipated.

In conclusion, it would certainly seem that much more progress had been made in the development of those methods of investigation on the Continent and in America than in this country, a state of things which it was to be hoped would be altered in the near future.

Mr. Neville said he had been asked to give some information regarding recent successful seismic work which had been carried out, and he proposed to give a short summary of some of the work which had been undertaken in different parts of the world. Salt domes had been located and outlined in the oil district north of Hanover, and also in Texas and Louisiana. Work had been carried out in Texas and Louisiana by the Seismos Corporation of Hanover during the past seven years, and since the introduction of geophysical methods fifty-four new salt domes had been discovered, twelve by means of the torsion balance and forty-two by means of the seismograph. Many of the salt domes so located had since been proved, as the result of drilling, to be oil pools. Similarly, anticlines in Mexico had been located and outlined by the seismic method.

In many of these cases the seismic method was used for the purpose of reconnaissance, and vast tracts of country were covered by the method. In some cases other methods were used in combination; i.e., more detailed work was done afterwards on likely areas by means of the torsion balance. The saving of cost by the use of the seismic method was enormous, and in the great race which had taken place in the past few years in America to discover salt domes the method had proved invaluable. In other parts of the world anticlines had been located and outlined and the seismic method had been used very successfully, not only in England, but in other parts on ore deposits.

Mr. W. H. Fordham, in reply, said the point raised as to whether electrical methods had been used with success to locate oil was a question of fact, and until the facts were published and vouched for by reputable people it was a little difficult to accept them. As far as he knew nothing had yet been published by anybody who was known and could be trusted showing that oil had been located by an electrical method. He had no personal experience of oil having been located by an electrical method. It was known that electrical methods had been tried in different parts of the world for finding oil, and the members would, he was sure, be extremely interested if they could obtain some knowledge of the result of those surveys.

He understood Mr. Bateman to say that the inverse cube law was not applicable to the inductive method. Dr. Mason went into the whole of that question a year ago in the article to which reference was made in the bibliography attached to the paper,[4] and there stated that it was applicable. Personally he failed to see how any other law than the inverse cube law could be applicable, so that he was afraid he must join issue with Mr. Bateman on that point. With regard to the radiometric method, the method to which he had referred dealt with penetrating rays; and as far as he knew the older method introduced by Dr. Ambronn dealt with softer rays. The whole question of radio activity needed investigation, and if it was carried out would probably lead to most interesting results.

He was sure the members were very grateful to Mr. Neville for the information he had given in regard to the successful application of the seismic method. It was admitted that the seismic method was being widely and successfully applied. The only difficulty was to get facts, but there could be no doubt that the seismic method was the most useful method that could be employed at the moment for locating certain types of oil structure.

The President said he was sure it would be the desire of those present that, in the name of the Institution, a very cordial vote of

thanks should be passed to the author for having brought such an important subject to the notice of the members in such an entertaining and instructive manner.

The resolution of thanks was carried by acclamation.

At the conclusion of the meeting **Mr. T. G. Madgwick**, Petroleum Engineer of the Department of the Interior, Canada, showed and described some lantern slides illustrative of oil operations in the Turner Valley, Alberta, Canada.

The following written contributions to the discussion were subsequently received :—

Dr. Donald C. Barton : It is very enlightening to compare the present geophysical methods to a geophysical method which has become so integral a part of geology that its close connection to physics is only dimly remembered by most geologists. The petrographic microscope is a geophysical instrument which one type of a geologist uses to see through his rocks or minerals to identify them, just as another type of geologist uses his torsion balance, magnetometer, seismograph or electric instruments to see down into the earth's crust to identify certain phases of its composition. The petrographer needs a very considerable knowledge of mathematics and physics, particularly optical physics, to understand what he does with his petrographic microscope. My impression is that, as a matter of fact, the petrographer needs to know more physics than a torsion balance specialist, a magnetometer specialist, or a seismograph specialist of the same grade. The physics and the physical instruments which the petrographer and which the applied geophysicist use in practical work are routine, and the problems which either meets in practical work primarily are geological and not physical. It is the physicist who at present is playing with methods of determining the atomic structure of minerals ; and the physicist presently will standardise the instruments and methods and the petrographer will take them over as a routine tool for the identification of rocks. Similarly in applied geophysics, there is and probably always will be a place for the physicist in research laboratories of applied geophysics, but in the field application of the methods, the important problems are geologic. Petrography is one of the branches of geology and in general no one would think of using a physicist on the usual type of petrographic work, or much less on the usual type of petrologic work. Similarly, the applied geophysical methods of mapping geologic structures are, or at least should be recognised as a branch

of geology, and the geophysicist who actually applies the method to mapping geologic structures should be a geologist who has had good training in physics and mathematics of his methods. The rather common belief at the present time, that it is necessary to use a physicist to make a geophysicist, seems very unfortunate and not for the best interests of the present application or of the future development of the methods. A geologist with little knowledge of physics and mathematics, and no training in the theory of geophysics, on the other hand, will make no better a geophysicist than a similar man without a course in petrography would make a petrographer.

A student in applied geophysics should receive the same broad fundamental geological training that a student in petrography does, with the physics and mathematics of the geophysical methods replacing the physics and mathematics of petrography.

Dr. Arthur Wade : This paper brings before us the oneness of science in spite of our endeavours to segregate it into leaky compartments which we label Physics, Chemistry, Geology and so on. Every one of the various branches and phases of Science is now called upon for aid in the search for oil. I am told that the headphones pictured in connexion with the use of the Electrical Method are due to a development of the stethoscope used in Medical Science.

We have now reached a stage in the development of geophysical surveying when it seems to be of greater importance to tell the public what the limitations are which limit the use of such methods, what geophysical instruments can not do, than it is to tell them what can be done by the use of geophysics, and I am glad to note that Mr. Fordham has made this a feature of this paper. Every week I hear of claims being made in connexion with geophysical surveys which I feel sure cannot and will not be upheld by subsequent investigation, and money is being spent with hope and enthusiasm in directions where it can only result in waste and discouragement. This must eventually bring about a setback and a revulsion of feeling, which is altogether undesirable, unless steps are taken to check a misguided exploitation of geophysics.

Mr. Fordham has done us a very good turn if he has, by means of this valuable paper, stimulated all of us to greater and more active interest in geophysics. More especially do I commend to the notice of all concerned with the part which British Scientists are expected to play in assisting in the development of the Empire Mr. Fordham's suggestion that a Geophysical Institute should be established. The sooner that is done the better it will be for the petroleum and mining interests of this country and of the British Empire in general.

Mr. H. B. Bateman : I agree with Mr. Fordham that the success of geo-electrical methods in locating oil strata is a question of fact, and I adduced one or two instances in the course of my remarks at the meeting in support of this.

Regarding the relation of the strength of the indication to depth, I agree that the inverse cube law applies equally to the electrical as to the gravimetric and magnetic methods; what I desired to point out was that in the former case the indication depends on the strength of the impressed forces, which forces can be controlled, whereas in the latter two cases one is dependent entirely on forces which cannot be augmented or controlled.

Capt. H. Shaw : While it is most desirable to direct attention to the great possibilities of geophysical methods of prospecting, I think it is equally important to point out to the oil geologist that these methods are not universally applicable, and cannot be used with impunity in the search for oil. Each method, while having useful characteristics, has also its limitations, and it is desirable that these should be properly understood. No good will be done to this young science by over optimistic claims and promises, and it is of the utmost importance that the methods should be employed with discretion and caution.

Speaking generally, geophysical methods are not employed to locate or detect oil directly, but they furnish particularly convenient means of locating certain structures, e.g., salt-domes, with which oil is known to be associated, and it is to this fact that the science of applied geophysics owes its rapid development. The salt domes of the Gulf Coast area provide hardly any surface clues to their existence, and, apart from wild-cat drilling, geophysical methods provide practically the only means of locating them. Fortunately, the salt plug possesses physical properties noticeably different from those of its surroundings, and full advantage is taken of this fact in the various methods. In the location of salt-domes, the seismograph and torsion balance have showen up to great advantage, while useful work has also been done by the magnetic method. The seismic method leads the way, with well over 50 domes to its credit, the bulk of which were located by the Mintrop Seismograph and the Karchei Geophone. The seismograph has proved successful for the location of deeper domes, but the torsion balance appears to be preferable for shallower ones, and particularly for detail work such as the accurate location of the edges.

The various electrical methods are undoubtedly of greater use in the search for metallic ores than for oil, and, as Prof. Truscott has said, it is to the electrical methods that the mining engineer

must look for the best results, unless for some reason the locality should prove unsuitable to their application.

I would like to congratulate Mr. Fordham in having traced and recovered Walker's horizontal variometer after it had been regarded as lost, and I am hoping that he may be able to give us further information about this most interesting instrument at a later date.

There is little doubt that the greatest difficulty in modern geophysics lies in the interpretation of the field results, but experience is proving that this work can be performed with reasonable accuracy, and it is only in cases of more complicated subterranean conditions that exceptional difficulty is encountered.

Under certain circumstances it may be desirable to run two or more of the methods over the same area, so that verification of the interpretation is obtained.

An intimate collaboration between the geologist and the geophysicist is, of course, essential to produce the best results, and neither can hope for the most successful application of these methods without the assistance of the other. It is to be hoped that the petroleum geologist will make his particular problems known to the geophysicist, so that the geophysical method or methods most suitable to the particular problem may be chosen and efficiently applied.

Mr. A. Broughton Edge: In presenting this comprehensive and well-balanced paper, with its carefully selected series of abstracts from current geophysical literature, the author has performed a valuable service—particularly in view of the fact that so little has been published in this country on geophysical work in general, and that, as a result, there has been little or no opportunity for serious discussion of the subject.

At the present time geophysical methods of exploration are being made use of to a rapidly increasing extent—principally in connection with oil and mineral exploration—and it is very necessary that the nature of the methods, and their limitations, as well as their useful applications, should be made more familiar to those engaged in these industries.

In his prefatory remarks the author refers to the difficulties which at present limit many of the useful applications of geophysical methods, and he points out, for example, that although work of the greatest value may be done in determining oil-field structures, as yet there is no recognised technique for the direct location of oil—a statement which, I think, will be agreed to by most geophysicists. A little later in his paper, when referring to electrical methods and their application to oil prospecting, he suggests that the low electrical conductivity of oil-bearing sands

and salt beds is the physical factor which should be made use of. This may be so in special cases, but, as a rule, I think that it is the relatively high conductivity of associated brine accumulations which affords greater possibilities and which in a number of cases has led to the employment of geo-electrical methods in oil-field work. Of course, under favourable circumstances, electrical methods may also be used in determining structural features, and recent work by French investigators has shown that effective results may sometimes be obtained electrically in a more expeditious and economical manner than is possible with gravimetric and seismic equipment.

In the section dealing with the seismic method, a description is given of the Mintrop seismograph, an instrument representative of the type of mechanical seismometer now being used very extensively and which, for large scale operations where speed of work is the important factor, is probably more effective than the multiple string galvanometer-microphone recording systems which have also been developed. The latter, however, may prove to be of very considerable value for certain kinds of seismic investigations—particularly in cases where the lightness and comparative simplicity of the equipment may compensate the necessity for employing cable connections between the several microphone stations and the recording instrument.

In his summary of geo-electric methods, the author makes one or two statements upon which comment may be made, although, in view of the general character of the paper, perhaps they are hardly called for. For example, in the case of the Self-Potential method, it might be inferred from the paper that natural polarisation effects are limited to sulphide deposits, whereas the method may also prove effective in other cases, such as graphite occurrences and, under special circumstances, in connection with saline water problems.

In describing the Resistance Method, in which current is passed through the ground between two earthed electrodes, it is stated that the size of the current depends on the conductivity of the beds between the electrodes. In general this is not the case, and the early failure of the method was due to the fact that the size of the current depends, not so much on the conductivity of the intervening ground, but on the nature of the electrode contacts and on other conditions in the immediate vicinity of the electrodes. As the author mentions, improvements in the resistance method have been made during the last few years and satisfactory results are now being obtained. The rapid reversal of the current is an important factor in reducing the effects of polarisation and of

natural earth currents, but a more notable advance in the method is the adoption of a four in place of a two-electrode system, as practised by Gish and Rooney.[1] The four electrodes are equidistant and are placed in line, potential differences being determined between the inner pair while the source of current is applied to the outer electrodes.

In Surface Potential work, using an alternating source of current, it is common and convenient practice to speak of "equipotential lines," although in theory the out-of-phase condition of such an alternating field precludes their existence. Nevertheless, in practice these lines can be plotted and the general distribution of current may be determined by this method in a very convenient and expeditious manner. As a means of locating conductive bodies within 200 feet of the surface, and for purposes of reconnaissance, there is much to be said for the surface potential method which has a number of important discoveries to its credit.

In the Inductive Method, it might be gathered from this paper that all that is required is equipment for determining the directional characteristics of the electro-magnetic field and possibly apparatus for measuring intensities. For a satisfactory application of the inductive method it is necessary to go further than this, and many of the most recent developments are particularly concerned with the investigation of the out-of-phase relationships between the primary and the induced fields, since these are more definitely related to the sub-surface conductivity conditions.

With the author's closing remarks I am in entire agreement, and there can be little doubt that all who are concerned with geophysical work in this country are anxious that active steps should be taken to promote the development of geophysical methods within the Empire. In view of the progress made on the Continent and in America this is becoming a matter of great urgency, and the formation of a Geophysical Institute or a Department of Applied Geophysics at one of the universities are proposals which deserve the strongest support.

In lieu of a written communication, Professor **Koenigsberger** sent copies of the following articles recently published by him :— "Field Observations of Electrical Resistivity and their Practical Application[48]," Tech. Pub. 129, Amer. Inst. Min. Met. Eng., 1928, "Über Vertikalerdstrom," "Über den Einfluss von Geländeunebenheiten auf das erdmagnetische Vertikalfeld," Gerlands Beitiäge zur Geophysik Bd. xx, Heft 1s. 2d., and heft 3s. 4d., 1928, Leipzig, and "Über die Wärmeentwicklung im Kalisalz durch das radioaktive Kaliumisotop," Kali, No. 17, 266, 1928. Halle.

[1] Terr. Mag. Vol. 30, No. 4, 1925.

The first refers to the work of Gish, Rooney, Hotchkiss and Fisher[46], explains the theory of resistivity measurements, and describes a four-electrode system adopted by himself, an alternating current, Wheatstone bridge and telephone being used.

This is followed by an account of a number of experimental investigations carried out by the new method.

In the second article evidence is produced to show that potential increases with depth, and it is pointed out that experiments in an uncased dry hole would decide the matter, which, from the point of view of pure geophysics, is of great interest.

The third article goes into the question of terrain corrections in magnetic surveying, and gives some tentative rules.

The fourth concludes that the temperature gradient in Polish mines is not due to radio-activity.

Mr. W. H. Fordham in reply, wrote :—

The noticeable feature of the written discussion is a desire to show that important points in connection with electric prospecting have been overlooked. This being so, it may be permissible to deal with electric methods at some length in this reply.

(*a*) *Self-Potential Method.*

This was treated shortly in the paper, as it is unlikely to prove useful in Oil geology. In any event the present paper is intended to be read in conjunction with the previous contribution of October, 1925, where the phenomenon of spontaneous polarisation was discussed at greater length, and a reference given to the later work on the subject.

(*b*) *Resistance Method.*

A large percentage of the resistance of the circuit is, of course, due to the earth resistance in the immediate neighbourhood of the electrodes, and it was not until steps were taken to reduce and measure this resistance that the method became practicable.

(*c*) *Surface Potential Method.*

Schlumberger ([46a, p. 31]), in the account of the development of his method states that he originally experimented with an audio-frequency alternating current in the primary circuit and a telephone in the secondary, but found unexpected difficulties, and therefore adopted the continuous current.

In this connection Jouawst's little book, " La Télégraphie par le Sol " (Chiron, Paris, 1924) is well worth consulting, as it throws much light on the behaviour of alternating currents flowing between earth electrodes.

The difficulties in the use of an alternating current, due to inductive effects between the primary and secondary circuits, phase

differences in different parts of the field, etc., are discussed at some length by Ambronn,* and the methods to be adopted for minimising them explained. For instance, he suggests that the earth electrodes should be placed at a considerable distance apart, and only the middle third of the area between the electrodes examined.

In the Elbof method the earth electrodes are placed near together, usually 100 metres apart, and the area round both electrodes surveyed. In this method the direction of the equipotential surface is observed with a frame aerial.

(*d*) *Inductive Method.*

A number of methods have been evolved with the object of locating conductors through the currents induced in them. No clear descriptions, unless patent specifications can be called clear, of these methods exist, the simplest, which is admittedly incomplete, being due to Dr. Mason.[4]

There appears to be difficulty in substantiating the claims made for inductive methods. That is to say, at the meeting of the Canadian Institute of Mining and Metallurgy in March of last year[45] a number of electric methods were discussed, and it was stated that the results obtained up to that date in parts of Canada were not encouraging. Thus, Mr. Macgregor remarked (p. 677) :—" You have only to remember that during the past two years, hundreds, perhaps thousands, of conductors have been located in Northern Quebec alone, yet not a single ore-body, and, as far as I know, not a single measurable sulphide body, has been found."

Electric methods have not yet been widely applied in Oil geology, one reason probably being the cost of surveying. The methods are comparatively cheap for local surveys, but the cost of seeking large structural bodies over wide areas is prohibitive, and, in spite of Mr. Edge's opinion to the contrary, is enormously greater than when the seismic and, probably, very considerably greater than when the gravimetric method is used.

This subject of Electric surveying for Oil is referred to on page 372 of *Petroleum Development and Technology in* 1927 (Amer. Inst. Min. Met. Eng.) in the following words :—

"(4) *Electric Methods.*

"A. These make use of alternating or direct current. They depend on the conductivity of different minerals and rock-petroleum being a nonconductor, oil sands sometimes a conductor, and salt water or salt sands a good conductor. Generally speaking, they are more serviceable in locating ores than oil deposits.

* Elements of Geophysics. London, 1928. P. 169 *et seq.*

"B. Most of these methods make use of alternating current and are modifications of Professor Schlumberger's work. Under this head come the Elbof method, which attempts to locate oil directly by the non-conductivity of petroleum, and the Lundberg method which attempts to locate it indirectly by mapping the outlines of a petroleum deposit by use of the conductivity of the high peripheral salt-water-filled inclined beds.

"D. None of the electrical methods have been sufficiently perfected to make them trustworthy for oil work, though improvements will undoubtedly come."

And on page 374 (remarks by Dr. Barton) :—

"The electric method has interesting possibilities, because it is the only one of these methods that acts on any principle that allows the direct determination of oil, on account of the high resistivity of oil, and there is the theoretical possibility that the method may be developed ultimately so we can tell where the oil is and not worry about mapping structure and hoping that the oil is where it should be on the structure. The Elbof people claim that they are able to do it, but there seems to be a great question about it. The Gulf Production Co. gave them a tryout and say that although there are interesting possibilities in the method it was not worth while fooling with at present. The Humble Oil and Refining Co. also has tried the method out; it was used in the Kingsville field, which is somewhat spotted, and I gather that there have been about as many successes as failures and about the same degree of success as if the predictions had been based on chance."

These extracts are interesting in view of Mr. Bateman's statement that the results mentioned by him show that oil can be located by the Elbof method.

The only other point arising out of the written discussion is Mr. Edge's dictum that the multiple string galvanometer-microphone recording systems may prove of considerable value for certain kinds of seismic investigations, in spite of the necessity of employing cable connections between the several microphone stations and the recording instrument. For detailed surveys of ore-bodies this may be correct, but for ordinary large scale oil work radio signalling is essential. Carlton's opinion on this matter is clear, for he reports ([25, p. 207]) :—"Radio has made the use of the seismograph practical as a method of geophysical exploration. No other kind of communication is practical or available. The use of wire for communication would involve the installation and dismantling of from 50 to 120 miles of wire line per day for each seismograph party in operation."

Time Lapse in Engineering Construction.*

By A. C. Vivian, Assoc.M.Inst.C.E. (Associate Member).

The subject of this paper is an analysis of some of the details of engineering construction work which affect the completion date of new plant.

Its scope is limited to the construction of Chemical Plant abroad, and it is based on general constructional engineering principles applied to a particular type of work.

No attempt is made to offer any ingenious short cut for rapid construction. The author supports the obvious conclusion that efforts to reduce time lapse are best concentrated on an accurate knowledge of existing routine and a careful attention to detail.

To present the subject in concise manner certain postulates are stated which limit the scope of the analysis to the type of work covered by these postulates; and the periods of time erected so to speak on these foundation postulates, whose component parts are measures of the total time lapse between inception of a plant and its completion, are then analysed.

The postulates are :—

(1) That there is an Inside Engineer or Consulting Engineer directing operations and an Outside Engineer or Resident Engineer at site who works to the plans and specifications provided by the Consulting Engineer.

(2) That there is an inception period during which the main features of the proposed plant are outlined, costed and offered for sanction corresponding with the preparation and dispatch of a tender comprising design and price which a manufacturer offers as a basis for a contract for carrying out work.

(3) That the term sanction used in this paper implies that the plans prepared in the inception period are authorized to be executed for the estimated cost corresponding with the order which the manufacturer receives after a successful tender.

(4) That the date at which the Inside Engineer can exert control over time taken is the date when sanction is given to proceed

* Paper received December 10th, 1928.

with the scheme. Similarly the date when the Outside Engineer can exert control is the subsequent date when he is in possession of detailed plans.

(5) That where alterations or site conditions entail an increased expenditure, sanction must be obtained before the work is proceeded with.

(6) That when sanction to proceed is given, the whole of the proposed work has been roughed out in sufficient detail for a comprehensive estimate of cost to have been prepared, which should normally be sufficiently elastic to preclude delays due to alterations or site conditions.

(7) That in the docket of information at the time of sanction is included all relevant facts required in order to purchase and erect the desired plant.

(8) That all important drawings and complete information are passed, before the date fixed for commencing erection, to the outside staff who are to erect the plant.

(9) That material is ordered and shipped and advices sent to site in time to avoid discontinuities in the erection programme.

(10) That the site selected for new plant, although it may be close to existing plant, or may encroach thereon, will be available solely for construction purposes to the exclusion of any other operations.

(11) That the plant shall be erected as designed and detailed or, if alterations are imposed either owing to site difficulties or changing requirements, an adequate time allowance must be made for the discontinuity thereby occasioned in the erection programme, as well as for the time taken to obtain sanction.

Analysis.—The periods built on the foregoing postulates are :—

Development Period or time lapse between sanction and the commencement of digging foundations at site.

Erection Period or time lapse between commencing foundations and completion of plant (*i.e.* start of preliminary trials).

Overall Period or time lapse between sanction and completion.

Development Period.

General.—The development period is obviously accelerated when the information collected during the inception period before sanction is as full and complete as possible. Headings suggesting details as to site conditions which must be known before a plant can be completely developed are given in Appendix A.

The development period exerts an influence throughout the whole of the overall period since the principle involved in saving time is to foresee eventualities and make adequate provision for them.

Full information even if to some extent redundant is probably preferable to minimum information. This applies not only to information from site and from the expert to whose designs the plant is being developed ; but also during the development period to the information given in full on copies of orders and correspondence in general where a few lines of typing saved may involve the recipient in hours of work in a labyrinth of cross-references.

Filing Information.—The opinion is expressed that it is easier to trace a letter or document by its chronological sequence than by any other method of classification.

A great deal of office time can be used up in making frequent cross-references to several files.

The conclusion is confirmed that it is best to collect from beginning to end all information arranged in chronological order upon one file or succession of files.

Drawings.—Drawings prepared during the inception period are best limited to simple design drawings and surveys. Design drawings often suffer from a lack of information which could have been remedied by notes written thereon in lieu of attempts to make detail drawings.

Detail drawings are essential before plant items can be ordered, but a great deal of time can be saved where the minimum amount of detailing of fittings is done and the maximum amount of time is spent on scheduling the material required.

The two primary purposes of detail drawings are :—

(1) To enable material to be ordered and manufactured as quickly as possible, and

(2) To enable the Resident Engineer to build the plant in accordance with the design.

These primary purposes are sometimes submerged in a desire to put an elaborate finish to the general arrangement drawings. In particular the work of the Resident Engineer is greatly facilitated when he has a general arrangement of the whole plant in his office and a number of detail drawings, each complete with its relevant schedule of material printed thereon, which he can issue to his staff of outside erectors.

An appreciation of this principle during development will save considerable erection time.

Material.—The first construction materials needed at site are concrete, foundation bolts and reinforcement, and timber formwork.

It is desirable from the Outside Engineer's viewpoint to order standard sizes of bolts, etc., wherever possible and to have them at site by the time that the foundation plans arrive. The extra cost entailed by cutting to waste (even if necessary) will generally be negligible compared with the cost of delay in commissioning the plant.

The time lapse between sanction and the last order for material is a measure of the difficulty of developing the details of the plant. Pencil drawings left for finishing and tracing till after the material is ordered will reduce this period where such a procedure is possible.

First Information to Site.—The first detailed information wanted at site includes :—

(1) A full general description of the plant.
(2) Extent of site, access and clearing required.
(3) Foundation drawings.

Shipment of Material.—In considering time lapse due to shipment it will be found simpler to count the time between date of order and arrival of the material on site, since for various classes of goods required the time lapse in getting them overseas is a variable function of :—

(1) The time required by the manufacturer to produce the material (including inspection) which obviously varies largely with different material.
(2) The accessibility of the place of manufacture to port of shipment.
(3) The number of places of call into which the shippers may be liable to put.
(4) The difficulties of off-loading and conveying the material from nearest available port to site, and
(5) The number of sailing days between port and port.

In order to assign a time lapse covering shipment of material to site it is necessary to acquire from previous records an estimate of what is a generous time allowance to cover for all reasonable fluctuations in the variable functions enumerated.

In Appendix B are given estimates for certain classes of material. The times refer to a shipping port in the U.K. and a site abroad.

Invoices.—In practice it is impossible to arrange for material to arrive on site in the precise order in which it is to be erected. Early information is therefore wanted by the resident engineer well in advance of the probable arrival of the material, so that he can arrange his erection programme to suit the exigencies of deliveries from contractors' works and of shipments.

This information the invoice provides. The invoice is prepared by the supplier of the material and includes a complete specification of the material in detail, numbering and contents of packing cases, shipping marks, name of ship and date.

Where "short shipments" occur—that is, where the material is left at the docks and not shipped as invoiced, immediate information should follow to site. If the consulting engineer at home and his resident engineer at site each have a copy on their files of all the invoices, the work of verifying the despatch and receipt of every item of material is greatly simplified and time is saved.

Alterations.—The completion of the development period must vary largely with the completeness of the scheme at the time of sanction. Where radical alterations occur during the development period owing to changing conditions, the period between sanction and last order placed and complete information to site may be a very lengthy one.

In general, nearly every alteration imposes some delay on commissioning date, nor is the magnitude of the delay in any way necessarily proportional to the amount of alteration called for.

Appendix C schedules certain details which have to be looked into when alterations are necessary.

Falsework.—The engineering term "falsework" refers to all temporary work, form work and so on which have no place in the finished plant.

The term is borrowed to imply also the extra work entailed both in development and erection by incomplete details of information or by alteration.

An important point in reducing time lapse in engineering construction is to avoid a lot of falsework, firstly, by providing full information; and, secondly, by having an understood routine for dealing with alterations.

This is particularly the case where the postulate that sanction must be obtained before increased expenditure occurs is rigidly enforced.

Erection Period.

General.—The continuity of the erection programme depends largely on the development period. Details referred to in this erection period section are, therefore, first of all, the concern of the inside engineer.

Appendix D provides a list of headings which will suggest others for any particular plant. These headings refer principally to falsework and include those details into which the resident engineer will look as long as possible before the erection period is due to start.

The items summarised include tools, appliances and machinery, labour, timber for formwork, construction drainage and all those details which must be foreseen and dealt with if time lapse is to be kept to a minimum. Appendix E summarises details which may prevent discontinuities in the erection programme.

Erection Ratio.—In examining schemes after their completion with a view to estimating probable completion dates for new plant, a ratio well worth examination is the ratio of erection period to overall period.

Such consideration serves to keep in mind the intimate relation between the development and erection periods. Where the development period is long owing to the mass of detail to be handled, the erection period is likely to be proportionately long.

In advancing what the author believes to be a new method of estimating time lapse in building plant, the suggestion is made that past records will provide a clue to what the erection ratio should be for the new plant, and that this method will probably produce as accurate results as a detailed schedule of times which may in actual fact give a cumulative error.

In Appendix F will be found a table showing development, erection and overall periods in months for various values of the erection ratio.

A development period of less than three months has not been considered, because for a plant of any size a month will elapse before drawings have been developed sufficiently for the first orders for foundation material to be placed, and it is unlikely that this foundation material will be on site abroad before a further two months have passed.

The co-operation between the engineering staffs at home and on site are reflected in the erection ratio, which also allows for the human element in the drawings, the ordering, shipment and handling of material and the labour available for erection.

Different plants involving the same type of erection should have, for any particular locality and engineering staffs, the same erection ratio. With the commencement of the erection period it should then be possible to forecast accurately, barring unprecedented weather, breakdowns and alteration, the completion date by computation from the erection ratio and the actual length of the development period.

Clearing Site.—In choosing an erection ratio it must be assumed that sufficient information will be at site soon after sanction date to enable the site to be prepared before the end of the development period ready for the erection period to commence on schedule time.

In other cases it would appear useful for the convenience of future estimating to introduce a special site clearance period attributable neither to development nor erection periods.

Labour and Material.—The most important factor influencing time lapse in erection work—namely, quality, both of labour and material, does not lend itself to general analysis, but requires study for each individual case. Time is saved where sufficiently accurate records of labour and climate are available for use during the development period so that the details of the plant may be suited as far as possible to conditions at site.

Completion.—The erection period extends up to the time of trial starting up, and it is in the finishing details that a disproportionate time may be lost. Usually a plant looks nearly finished a long time before completion, and the last weeks or months drag on with little to show for the time taken.

The resident engineer, keeping this in mind, concerns himself a long time before completion date in checking over all those details—*e.g.*, gauges, instruments and minor connections which must be installed before the plant can be handed over for trial. A list of headings which will suggest others applicable to chemical equipments will be found in Appendix G.

Team Work.—Time lapse is regulated fundamentally by team work among the development and erection staffs. Among the interesting things which may be observed about a team are the reappearance of strongly-marked characteristics of the skipper and the better work which the team does when each man has a definite part to play in the game.

These and other traits, translated into engineering practice, have a profound influence on time lapse.

Appendix A.

No.	Information from site.
1.	Local materials available, e.g., stone, sand, water, bricks, lime, cement, hardcore, timber, etc.
2.	Details of local methods of construction which with the labour available it may be advisable to adopt.
3.	Local facilities for fabrication, workshops, foundry, etc.
4.	Off-loading facilities, docks, cranes, etc., railways and rolling stock capacity and details.
5.	Size and capacity of existing derricks and additional derricks and erection cranes needed.
6.	Available routes for conveyors, railways and runways, either permanent or for construction purposes.
7.	Quality of local labour available, labourers, fitters, erectors, riveters, welders, etc.

8. Pipe bending, cutting and screwing machines, welding plant and facilities for smithy work for special jobs on site or in workshops.
9. Site costs.
10. Prevailing wind and weather conditions and its effects on outside construction work.
11. Nature of ground, ground levels and surveys of site.
12. Adjacent plant, if any, and particularly existing plant or operations likely to interfere with erection.
13. Available routes for link-up pipework and route surveys with particular reference to high points, etc.

Information as to existing sources of supply or disposal of the following together with details of special fittings and connections for linking up :—

14. Incoming raw material for the new plant.
15. Disposal of products of the plant.
16. Steam, quantity, pressure and superheat available, details of boilers, etc.
17. Fuel supply, oil, gas, coal, etc.
18. Water, quality and quantity likely to be available, water pumps, drains and drainage plant.
19. Electric power and details of generators, existing transmission systems and effect of new load on power factor, etc.
20. Compressed Air Supply and details of portable compressors available, details of drive, etc.
21. Vacuum systems, capacity and existing duties.
22. Disposal of corrosive substances and effluents and local regulations relating thereto.
23. Any other available facilities.

Appendix B.

Shipment period estimate for certain materials comprising :—

(1) Manufacture and inspection.
(2) Rail to port.
(3) Shipping delays.
(4) Off-loading.
(5) Actual sailing days.

Class of Goods.	Covering allowance for variable time factors.	Shipment period if actual sailing days = 1 month.
Complete steel structures or steel framed buildings up to 250 tons	6 months.	7 months.
Special chemical equipment, welded vessels, etc.	6 „	7 „
Centrifugal pumps and motors, steel pipework and fittings to a pipework layout drawing	4½ „	5½ „
Firebricks and special brickwork	3½ „	4½ „
Standard pipe fittings	3 „	4 „
Steel pipe in random lengths	2½ „	3½ „
Standard electric fittings	2½ „	3½ „
Foundation bolts and nuts reinforcing bars and fabric, ex stock	2 „	3 „
All material, ex stock	2 „	3 „

Appendix C.

Whenever alterations are called for the whole plant needs checking over with particular reference to :—

(1) Increase of ground pressure which will be caused by added loads on existing foundations.
(2) Capacity of steam, water, electric, drain and other services to meet the alteration.
(3) Whether the alteration interferes with other parts of the design.

Appendix D.

Details affecting the starting date of erection work at site.

(1) Supplies of timber and carpenters for making forms.
(2) Supplies of cement, clean sand, ballast, water and hardcore, cement mixers and power for driving.
(3) Adequate reserve supplies of cement, hardcore, etc., should the nature of ground after excavation entail increased depths of foundations.
(4) Excavating machinery and drills for hard rock if required.
(5) Location of spoil banks and transport of excavated material.
(6) Piling machinery, sheet steel piling (if required) and adequate pumps for water-logged ground.
(7) Lighting for site if night work is required.
(8) Adequate provision for expansion and vent holes (if required) for furnace foundations.
(9) The provision of surface drainage away from foundations.

Appendix E.

Details which may prevent discontinuities in the erection programme are :—

(1) Foundation bolts, etc., on site before formwork and excavations are complete.
(2) The provision of as much space as possible alongside site where material may be dumped as required, and sorted.
(3) Plant and steelwork to be available alongside site in time for sorting before required for erection.
(4) The provision of access and space for derricks and winches for erection of large items of plant and space where such parts may first be rivetted or welded up.
(5) The provision of gas free and non-dangerous areas, where rivetting fires, welding plant, boilers, etc., may be located.
(6) Supplies of Carbide and Oxygen for Oxy-acetylene welding, spelter and acid for lead burning.
(7) Supplies of rivets, bolts and nuts and adequate spares ; coke for rivet fires ; snaps and rivetting tools.
(8) Compressors or compressed air supply for pneumatic tools.
(9) Supplies of electric cable, wiring, and fittings sufficient for the complete scheme.

Appendix F.

For various values of the erection ratio the following table gives certain corresponding values of development, erection and overall periods :—

Development Period. Months.	Erection Period. Months.	Overall Period. Months.	Erection Ratio. Percentage.
3	2	5	40
3	3	6	50
3	4½	7½	60
3	7	10	70
—	—	—	—
6	4	10	40
6	6	12	50
6	9	15	60
6	14	20	70
—	—	—	—
9	6	15	40
9	9	18	50
9	13½	22½	60
9	21	30	70
—	—	—	—
12	8	20	40
12	12	24	50
12	18	30	60
12	28	40	70

Appendix G.

Finishing details for chemical equipments :—

(1) The fitting of gauges and instruments.
(2) Insulation of pipes and vessels.
(3) Cutting into existing steam, electric, oil and other supplies, and drains.
(4) Lighting the plant.
(5) Testing and cleaning up the plant.
(6) Paintwork.
(7) Clearing up and making good site around the new plant.

The Properties and Analysis of Used Crank-Case Oils.*

By D. G. Pidgeon and H. E. Tester, B.Sc.

It has been observed generally that the lubricating oil used in the crank-cases of internal combustion engines undergoes serious deterioration during use. The importance of this fact to automobile engineers cannot be over estimated, since a great deal of wear in the working parts of a motor can be avoided by correct lubrication.

The chief causes of this deterioration can be summarised under four headings :—

(1) Accumulation in the oil of quantities of mineral matter carbon and dust together with minute portions of metal from the engine itself, which tend to make the oil abrasive.

(2) Decomposition, which sets in when the oil comes into contact with hot gases in the combustion space of the engine, especially when it is retained in hot places, such as under the piston crowns and behind the piston rings. This gives rise to the liberation of carbon, a small quantity of which becomes dispersed in the oil in a very finely divided state. Decomposition also gives rise to the formation of "cracked" products of lower boiling point and viscosity.

(3) Partial oxidation of the oil whilst it is hot and in contact with a fair supply of air, creating asphaltic compounds of high viscosity and little lubricating value. Some of these are insoluble in the oil and separate as sticky sludge, which may clog the oil ways.

(4) Dilution of the oil with unburnt motor fuel, which, if taking place to any extent, causes considerable lowering of the viscosity of the oil.

Barnard[1] considers that the diluents in spent oil are the most objectionable contaminants, and has shown that the rate of wear in an engine increases with the dilution, and that at dilutions above ten per cent. to fifteen per cent. it increases at a much greater percentage rate than the dilution. The following paper presents more precise information on the deleterious effect of the presence of diluents in crank-case oil.

The extent to which an oil becomes affected during use depends upon several factors, among which may be mentioned the following :—

* Paper received January 1st, 1929.

(1) The design, construction and condition of the engine under consideration.

(2) The type of fuel used and the working conditions of the engine. Heavy spirit used in winter will throw down a not inconsiderable quantity of diluent into the crank-case, especially as a rich and incompletely vaporised petrol/air mixture has to be used when starting and often when accelerating.

(3) The nature of the original oil. An unsuitable oil, which oxidises and decomposes rapidly, will soon be of little value.

Methods of evaluation of lubricating oils can be classified into laboratory tests and actual engine tests. The former, consisting of the determination of such constants as viscosity, flash point, carbon residue, sulphur, specific gravity, oxidation test, etc., must be considered in conjunction with one another and in conjunction with actual experience in determining the suitability of an oil. Engine testing, however, gives definite results if conducted under strictly standard conditions, and thus can be considered to be the only really satisfactory method of evaluation. It is in this respect that the examination of used oils becomes of paramount importance.

A number of samples of used oil derived from the same original oil (a medium grade motor oil of viscosity 146 secs. Redwood I. at 140° F. prepared from a mixed-base crude petroleum) were examined in the laboratory, and it was found that, while all the samples contained diluents of bad odour, some had higher specific gravities and viscosities than the unused oil. As a lowering of the values of both these constants was expected, they could be no measure of the amount of dilution which had taken place. A method was devised therefore to estimate the percentage dilution of the used oil. The procedure finally adopted is as follows: 150 c.c. of oil are measured into a 500 c.c. distilling flask, which has a bent side-arm, the flask being connected to a condenser and fitted with a cork carrying a steam pipe and a thermometer, which dips into the oil. The oil is warmed to 150° C. and maintained at this temperature, while slightly superheated steam is blown in until no more oily liquid collects in the graduated receiver placed at the end of the condenser. The distillate is measured and the dilution calculated as a percentage by volume. A blank experiment was made on new oil using these conditions, and it was found that after prolonged distillation only a few drops of oil passed over.

A similar method has been used by Flowers, McBerty and Reamer,[2] who maintained the oil sample at 165° C. and used slightly superheated steam to avoid "bumping" troubles.

The use of wet steam at 100° C. with no external heating of the oil, was tried, but this was found to give a smaller yield of distillate in each case. In the case of some synthetic blends using fresh oil and a heavy spirit (commercial spirit topped to 100° C.) only about 87 per cent. of the spirit was recoverable. The following figures illustrate this point :—

TABLE I.

Diluent in Synthetic blend.	Dilution Wet steam method.	Dilution Oil at 150° C.
%	%	%
2	1·7	2
5	4·3	5
10	8·7	10·1
15	13·4	14·8

The extent of dilution having been determined for each of the samples of spent oil (see Table II.), an attempt was made to discover the laws governing the relation between viscosity and dilution, but this was found to be impossible on account of the number of factors which influence the former constant. For instance, the viscosity of an oil decreases with dilution and increases with oxidation so that viscosity-dilution curves cannot be drawn. Similarly flash-point bears no relation to percentage dilution because the diluents extracted from each oil are not identical.

In view of this inconclusive evidence as to the actual condition of the used oil, experimental work was carried out to determine the actual lowering of viscosity with dilution. The distillate obtained from a number of dilution determinations was bulked, in order to obtain a representative sample sufficient in quantity, and this oil was examined. It was a yellow, sour smelling liquid, having a specific gravity of 0·802 at 60° F., and the following boiling range :—

Initial boiling point	108° C.
Volatile to 125° C.	few drops.
„ 150° C.	15%
„ 175° C.	55%
„ 200° C.	83%
„ 225° C.	91%
„ 250° C.	94%
„ 275° C.	96%
Total distillate to 300° C.	97·5%
Residue	1·5%
Loss	1·0%

It will be seen that the diluent consisted largely of heavy ends from the motor fuel, the balance being " cracked " products formed by the decomposition of the oil. On testing, the diluent was found to be decidedly unsaturated, and capable of absorbing the bromine

TABLE II.

ANALYTICAL FIGURES FOR CRANK-CASE OILS.

	Sp. Gr.	Flash-Point	Carbon Residue	Ash	Viscosity in Seconds. 70°	100°	140°	200°	Dilution.
Car A.		°F.	%	%	F.	F.	F.	F.	%
1 ..	0·918	130	0·88	0·07	879	267	112	51	7·0
2 ..	0·911	128	0·53	0·03	527	215	86	46	10·0
3 ..	0·914	132	0·95	0·12	620	228	92	50	9·5
4 ..	0·911	128	0·32	0·05	567	211	88	48	8·5
Car B.									
1 ..	0·919	150	0·88	0·10	771	276	106	49	9·0
2 ..	0·911	124	1·03	0·09	435	191	80	46	11·0
3 ..	0·904	120	1·26	0·11	436	174	76	46	14·0
4 ..	0·911	132	1·01	0·14	480	175	81	46	9·5
Car C.									
1 ..	0·924	208	0·61	0·02	1166	394	138	54	2·5
2 ..	0·920	208	1·26	0·16	1206	430	145	56	3·0
3 ..	0·920	206	1·36	0·05	1088	403	135	56	3·5
4 ..	0·919	190	0·79	0·16	868	314	110	52	4·5
5 ..	0·922	196	1·96	0·08	945	305	113	53	4·5
Car D.									
1 ..	0·926	225	0·93	0·12	1281	432	146	57	3·5
2 ..	0·920	207	0·45	0·02	1100	374	132	53	2·5
3 ..	0·922	212	0·80	0·06	1103	328	130	54	4·5
4 ..	0·922	222	1·30	0·13	1216	424	142	61	3·5
5 ..	0·920	180	1·21	0·09	920	308	112	52	4·0
6 ..	0·919	180	0·72	0·05	872	330	118	54	5·0
Car E.									
1 ..	0·917	192	0·79	0·04	1157	386	138	56	3·0
2 ..	0·919	178	1·09	0·14	1035	365	137	54	4·0
3 ..	0·923	168	1·22	0·09	1022	343	129	55	4·5
Car F.									
1 ..	0·922	174	0·63	0·05	1117	394	137	57	3·0
2 ..	0·922	190	0·67	0·09	1189	410	139	56	2·5
3 ..	0·920	184	0·88	0·10	985	353	131	56	5·0
4 ..	0·920	178	1·02	0·11	1105	374	131	55	5·0
5 ..	0·920	194	0·86	0·12	1202	405	142	55	2·0
Car G.									
1 ..	0·918	178	0·96	0·07	928	335	121	54	4·5
2 ..	0·920	164	1·36	0·10	860	325	115	52	6·5
Car H.									
1 ..	0·911	144	1·30	0·21	721	271	102	50	12·0
2 ..	0·907	132	0·78	0·15	631	346	96	53	13·5
3 ..	0·911	148	0·61	0·11	580	230	94	50	9·0
4 ..	0·912	180	0·88	0·12	610	254	95	49	9·0
Car I.									
1 ..	0·917	160	1·29	0·20	941	348	127	54	7·0
2 ..	0·911	128	0·99	0·16	551	244	91	49	10·0
3 ..	0·915	178	0·79	0·10	1041	381	140	61	5·5
4 ..	0·913	158	1·12	0·16	789	295	112	52	8·0
Original Oil.									
	0·923	440	0·24	nil	1285	432	146	60	nil

from half its own volume of saturated bromine water. The sulphur content was 0·13 per cent.

Quantities of unused oil, exactly similar to that used in the engine tests, were then blended with 3 per cent., 5 per cent., 7½ per cent. 10 per cent. and 15 per cent. of a synthetic diluent of the same boiling range as the above, and the constants of these blends determined. The results are given in Table III., and curves are appended showing clearly the effect of the diluent.

TABLE III.

CONSTANTS OF BLENDS, NEW OIL WITH DILUENT.

	Flash-point.	Carbon residue.	Viscosity in seconds.				
	Sp. gr.	°F.	%	70° F.	100° F.	140° F.	200° F.	Dilution. %
Uncontaminated oil	0·923	440	0·24	1285	432	146	60	nil
3% Diluent added	0·919	192	0·19	955	328	122	53	3
5% " "	0·917	172	0·14	765	275	105	49	5
7½% " "	0·914	156	0·13	562	215	86	46	7·3
10% " "	0·911	142	0·11	432	178	74	44	10
15% " "	0·905	130	0·09	280	125	61	41	14·8

It may be seen that when a medium grade oil has attained 10 per cent. dilution, it has acquired the properties of a spindle oil, while 15 per cent. dilution converts it to a light spindle oil. Such dilutions are common in every-day practice, while some experimenters, claim to have handled oils containing 30 per cent. of diluent, although this is beyond the experience of the authors.

Viscosities, such as those shown by these blends (Table III.) are, of course, never reached in actual samples of used oil, although a viscosity of 80 secs. at 140° F. in a sample with 11 per cent. dilution, has been observed (Sample B2. Table II.). By reference to the viscosity—dilution curve (Fig. 1), it can be seen that the viscosity of, say, sample I.1, would have been lowered from 146 secs. to 90 secs. at 140° F. by dilution alone, but that oxidation has caused the viscosity to increase to 127 secs. At the same time oxidation has caused the carbon residue of the oil to rise from 0·24 to 1·09 per cent. It is, however, at present not known if the oxidised products in the used oil, which cause the viscosity to increase, have any lubricating value.

It is by reference to the curves which have been drawn from the data compiled in Table III., that the samples, whose constants are shown in Table II., can be evaluated. In this instance, comparison of the lubrication of several different types of engines was the object of the tests made, but the method could very well be applied to the evaluation of lubricating oils, by running the same engine under standard conditions with a succession of different oils.

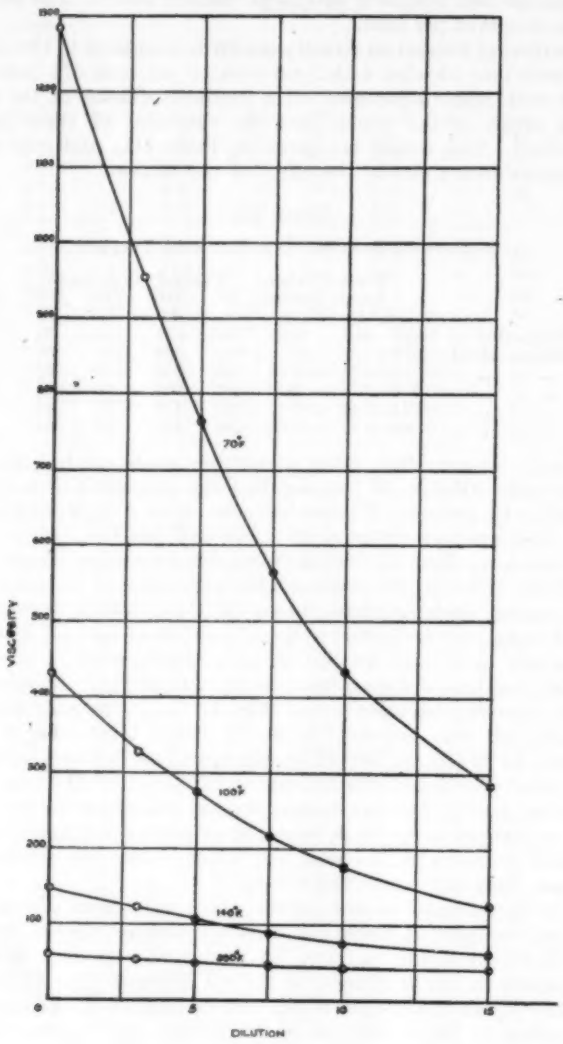

FIG. 1.

VISCOSITY—DILUTION CURVE FOR NEW OIL WITH DILUENT.

The percentage dilution depends largely on weather conditions; cold weather means a cool crank case, a cool water jacket and incomplete vaporisation of petrol. Apart from the above, however, the following inferences can be drawn from the data given in Table II., and hold good for periods of approximately even

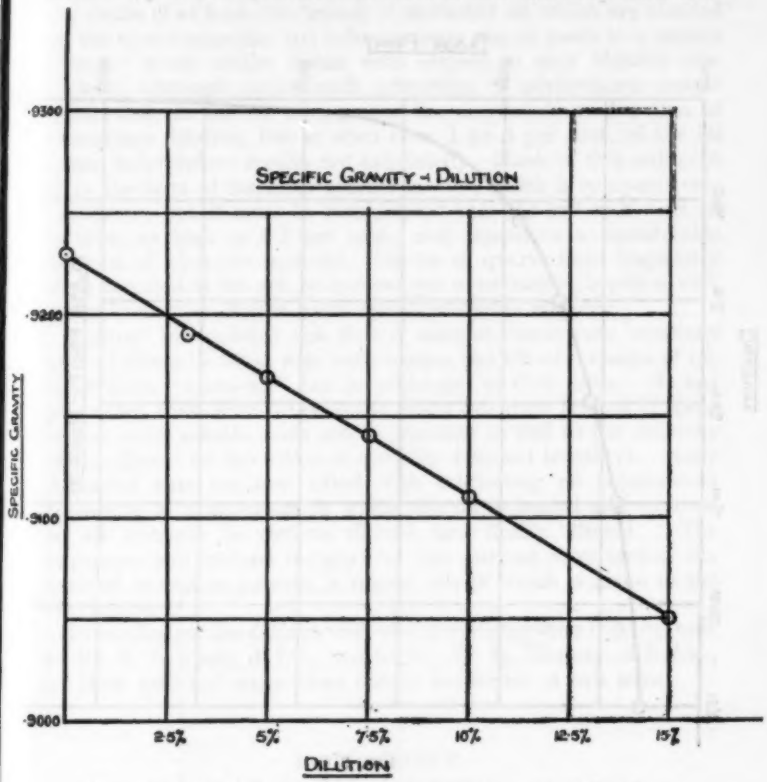

FIG. 2.

SPECIFIC GRAVITY—DILUTION CURVE—NEW OIL WITH DILUENT.

temperature:—Firstly, the percentage dilution in an oil reaches an approximately constant value for any particular engine, but this constant value depends entirely on the engine itself. This is in agreement with opinions expressed by McCoull[3] and Meston[4] and other experimenters who have shown that the point of maximum

dilution and minimum viscosity is reached in about 400 miles after refilling the crank case with fresh oil. From this stage the viscosity slowly increases, but the dilution remains approximately the same, and the oil slowly deteriorates with the accumulation of oxidation products and adventitious matter. Secondly, medium

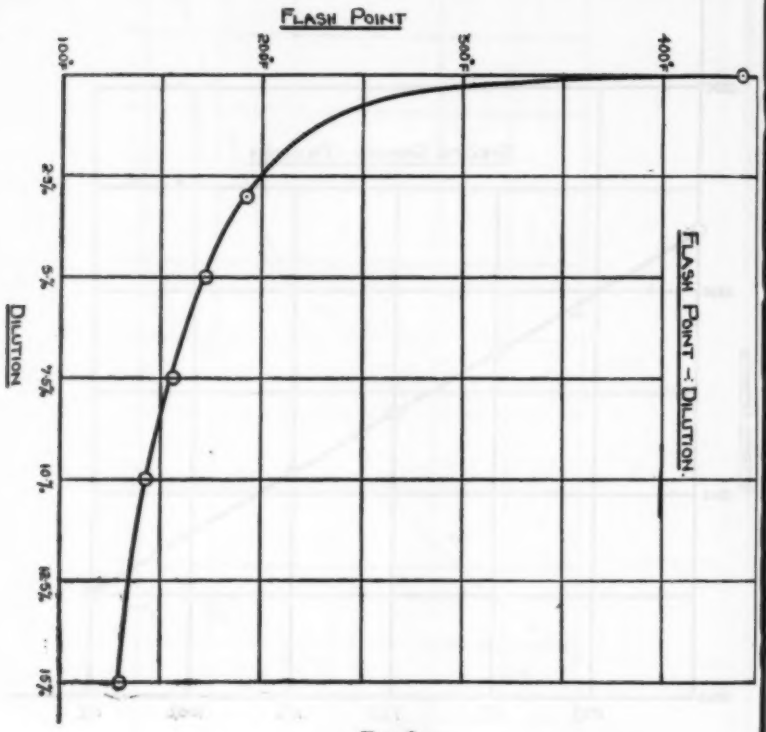

Fig. 3.

FLASH POINT—DILUTION CURVE FOR NEW OIL WITH DILUENT.

grade oil is obviously unsuitable for use in cars such as A and B (one make), and H and I (another make), because the constant percentage dilution present in their oils is such as to reduce the viscosity of the oil to well below the safe limit. With these types of engine, the only means of securing correct lubrication without structural alterations is to use a heavy grade oil.

A proposal was put forward two or three years ago to use an oil to which suitable diluent had been added to about the equilibrium percentage. This oil should not dilute further and should remain at the correct viscosity, except for a rise due to oxidation and a fall due to decomposition and so remain steady. The authors' are aware of at least two brands of marketed oil, which are blended on the above principle, and reference may also be made to a certain patent,[5] which makes claims with respect to such blended oils. Thirdly, although considerable quantities of adventitious matter accumulate in the oil during use, the amount is no function of percentage dilution, but is often from 1 to 3 per cent. of the oil (some independent results not tabulated). Much of this sediment is in the form of insoluble organic matter, which is comparatively innocuous, but it must be remembered that the ash of a used oil is often as high as 0·2 per cent., and represents a considerable amount of abrasive material. Grains of quartz have frequently been detected in the ash by microscopic examination, together with larger quantities of iron oxide and argillaceous material.

Meston[4] has pointed out that if suitable crank case breathers and oil filters be fitted with each engine, the life of a charge of oil, apart from "make-up" can be prolonged to 6000 miles. He has also noted that corrosive products which are often present in spent oils as water soluble acids can be removed as well as the majority of the diluent by the fitting of specially designed breathers. Many American cars are now fitted with lubricating oil regenerators consisting of evaporators in which the oil is heated and exposed to air currents to remove diluent and finally filtered. The apparatus and method required for this purpose have formed the basis of numerous patents, a typical one of which is given in the bibliography.[6]

In conclusion, the authors wish to acknowledge their indebtedness to Mr. S. Bowman, F.I.C., and to Mr. W. H. Thomas, A.R.S.M., for their help and suggestions during the course of this work.

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Air and Gas Lift Production Methods.

Precis of paper by C. B. ROACH (Student Member),

Students' Medal and Prize, 1928.

THE author has succeeded in this paper in considering most of the main points of this intricate problem. In the introductory comments on other methods of production, "Bailing" is referred to as an extremely tedious method carried out mainly in Russia, Galicia and Rumania, where labour is cheap. It is not so much a question of cheap labour, but the fact that "Bailing" is the effective method of dealing with oil wells which produce large quantities of water as well as oil, and in which the more modern methods, the subject of the paper, are frequently impractical on account of the formation of troublesome emulsions.

The author describes two methods of air and gas lift which he designates as the "Indirect" and "Direct" methods. The former method is now commonly known as Re-pressuring and some details are given exemplifying the difficulties accompanying this method and indicating the caution to be observed.

Mention might have been made where either method may be employed, but the dangers of excessive back pressure may be minimised by utilisation of both methods in conjunction. This is practised in various oilfields.

A considerable amount of interesting information is given in connection with the Direct method and the author has shown that he possesses a good knowledge of both the theoretical and practical side of one of the most important problems in Petroleum Technology.

The Present Methods of Determining the Constituent Classes of Hydrocarbons in Gasoline.

Precis of paper by DONALD A. HOWES, B.Sc. (Student Member). Students' Supplementary Prize, 1928.

IT is very doubtful if chemical analyses which only indicate the percentage of the various hydrocarbon types found in a motor fuel will ever be correlated with engine performances, yet it must be remembered that such analyses serve as very useful refining guides, especially in the case of cracked spirit. Unfortunately our knowledge of the chemistry of hydrocarbons—with the exception of those of the aromatic series—is very poor, and it is therefore a matter of difficulty to isolate the various individual constituents of any fuel, purely physical methods not being sufficient. At the same time it is important that the individual constituents of gasolines be studied separately, for nothing is gained by stating that a motor fuel contains, for instance, 50 per cent. paraffins or 10 per cent. olefines; under the general heading "paraffins" may be found compounds of both pro-knock and anti-knock characteristics, while various olefines can differ widely in their reactivities.

Thus it will be seen that present-day systems of analysis have severe limitations, although they must necessarily be employed for the lack of the very elusive ideal method of analysis which will give direct correlation with engine performances.

Before such a method of analysis can be devised a new classification of the hydrocarbons found in gasolines will be necessary, but it is difficult to see how this can be done.

For the estimation of the content of paraffin, naphthene, aromatic and olefine hydrocarbons in gasoline numerous methods have been described, but they all suffer from the fact that the typical reactions which these various classes of hydrocarbons undergo differ not in type but only in degree—in this connection the reactions with oxidising agents may be quoted.

No method of estimating paraffins in hydrocarbon mixtures has yet been described except that by difference, paraffin hydrocarbons undergoing no reaction peculiar to themselves. Naphthene hydrocarbons are very much akin to the paraffins and great difficulty is experienced in trying to separate these two classes of compounds when present in a mixture together. The only method at our disposal for the estimation of naphthenes, when mixed with

paraffins, is a purely physical one, and involves the determination of aniline points.[1] All paraffins are assumed to be miscible with an equal volume of aniline at a temperature of 70° C., that is, they all are supposed to have an aniline point of that figure, and, moreover, all naphthenes are supposed to lower aniline points to the same extent. The method is only approximately correct, for in the case of both naphthenes and paraffins their aniline points are not constant.[2,3,4]

The estimation of unsaturated hydrocarbons is perhaps the outstanding problem facing oil chemists to-day, none of the known methods giving accurate results. The need for a reliable method is great, for unsaturated hydrocarbons are extremely valuable constituents of a gasoline although the public has long been prejudiced against them. They are quite clean distilling liquids and are valuable anti-knocks, the di-olefines alone being the objectionable constituents.

The chief methods at present in general use for the estimation of unsaturateds are those depending upon halogen absorption and the use of sulphuric acid. In the first case the halogens employed are either bromine or iodine and several methods have been suggested, although the reaction involved is the same in all cases, the addition of two halogen atoms to the olefine molecule at the double bond ; a spirit thus being evaluated by its halogen absorption or bromine or iodine number. Such a figure can only be used for comparison purposes. It has no absolute significance unless the molecular weight and density of the olefines reacting be known. Such methods depending upon halogen absorption as have been suggested all suffer from the following disadvantages :—

1. Frequently the theoretical absorption is not obtained.
2. The absorption of halogen depends upon the concentrations of the reactants present and upon the time of reaction.[5]
3. Certain solvents have different specific actions.
4. Substitution of hydrogen atoms goes on simultaneously with halogen addition.
5. Very careful manipulation is required before concordant results may be obtained.

Of the older methods, only that of Hanus[6] is now used, and still finds favour in spite of the unique advantages of the newer McIlhiney[7] method, which presents a means whereby the amount of substitution occurring may be determined. The more recent method of Francis,[8] in which bromine is obtained by the action of dilute sulphuric acid upon a bromide-bromate solution and is absorbed by the olefine as fast as it is formed, is as yet but little used.

From time to time various methods have been suggested for the quantitative removal of olefines from hydrocarbon mixtures by means of sulphuric acid. This acid, when of the requisite strength, reacts with unsaturateds to form oxidation and polymerisation products, alkyl sulphates and secondary and tertiary alcohols. Of these the alcohols, which are formed from the lower olefines, pass into the acid and are eliminated, but unfortunately the polymers and esters being soluble in the unattacked spirit stay therein. The polymers are chiefly the dimers and still contain a double bond.[9]

Thus it will be seen that the method is unsound whatever particular strength of acid may be employed, seeing that the dimers are far less soluble in the acid than the parent olefine.

Much controversy has taken place over the minimum concentration of sulphuric acid required to remove olefines completely yet be without action on aromatics, but it is the author's opinion that no well-defined dividing line exists and that if the olefines be removed quantitatively by this means, aromatics are also affected.

For the estimation of aromatics by means of sulphuric acid, 100 per cent. acid is usually employed, although recent work by Kattwinkel[10] has shown that for high concentrations of aromatics such a strength of acid is not sufficient. Kattwinkel uses, in this case, a 98 per cent. acid activated with phosphorus pentoxide.

Various other methods have been suggested for the estimation of unsaturateds but are little used; these make use of the reactivity of olefines towards, among other compounds, nitrosyl chloride,[11] sulphur monochloride,[12] etc.

Aromatic hydrocarbons may be estimated by the 100 per cent. sulphuric acid method mentioned above, and also by means of a nitration mixture, by the use of preferential solvents and by other methods. In the sulphuric acid method the aniline point of the gasoline is determined before and after acid treatment, the difference in the two figures obtained being proportional to the aromatic content to within narrow limits, but only in the absence of olefines. Olefines lower aniline points to a lesser degree than do aromatics and hence possess a disturbing action.

This is far from being an ideal method, since certain higher aromatics, for example, hexamethyl benzene, are not affected by this concentration of acid yet do depress aniline points. Moreover certain branched chain naphthenes and paraffins may be dissolved by the acid.

It has also been observed that in sulphuric acid solution styrene will condense with aromatic hydrocarbons to give condensation products, and normal hexene will react with benzene giving hexyl benzene, and it is quite probable that other unsaturateds may

behave likewise. It is therefore imperative that all olefines and unsaturateds be removed from a spirit before an acid test for aromatics is carried out.

Egloff and Morrell[13] have used a nitration mixture of nitric and sulphuric acids for the determination of aromatics whereby a volume loss is registered, thus aniline points are not utilised. The objections to this method are (1) that some of the resulting nitro-compounds are soluble in the residual spirit, (2) the method gives results that are too low for low aromatic contents and too high for high aromatic contents.

The use of preferential solvents for the estimation of aromatics is very unsatisfactory although the use of dimethyl sulphate,[14] diethyl sulphate,[15] aniline,[16] and liquid sulphur dioxide has been suggested. Generally such methods can be of but little use, for the different classes and individual hydrocarbons have a mutual solubility far greater than the solubility in any solvent, which renders the estimation by extraction impossible.

Such are the difficulties which attend the separation of the four general classes of hydrocarbons, and the present review is an attempt to point out the disadvantages and inaccuracies of the present available methods. The author urges that future work be concentrated upon the properties of pure hydrocarbons, because only by this means can the inherent deficiencies of any method be made evident, and also, which is far more important, only by such a course can reliable data be obtained.

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INSTITUTION OF PETROLEUM TECHNOLOGISTS.

PERSIAN BRANCH.

FIRST ANNUAL DINNER.

THE First Annual Dinner of the Persian Branch of the Institution of Petroleum Technologists was held in the Restaurant at Abadan on October 3rd, 1928.

The chair was occupied by the Chairman, Mr. H. Y. V. Jackson, and about sixty Members and guests were present.

"The King."

The toast of "The King" was proposed by the Chairman.

"The Petroleum Industry."

Mr. H. Y. V. Jackson, M.C., M.Sc., in proposing the toast, said :—Ladies and Gentlemen, on this occasion of the first dinner of the Persian Branch of the Institution of Petroleum Technologist no apology is needed for introducing a toast to the Petroleum Industry. The subject is one which appeals to most of us ; firstly, by virtue of its intense interest, and secondly, because it provides us with our bread and butter. Perhaps some of the more commercially minded among us may consider the second appeal stronger than the first.

The Petroleum Industry is such a comprehensive one and embraces so many different interests that whenever the term is mentioned it is difficult to conjure up in a moment all that it really means. I would like therefore this evening to comment on some of the features of the Industry with a view to clarifying the somewhat obscured vision of its thousand and one activities. I will endeavour to unfold before you a short panoramic view of the Industry as a whole, but time will only permit me to touch on the higher lights, leaving the deeper shadows to be delved into at the more technical meetings of this Institution.

The first phase of the Industry which strikes one most is the extraordinary variety in its different ramifications. It provides a wonderful field of activity for practically every conceivable profession. Geologists, engineers of all classes, chemists, physicists, mathematicians, accountants, business experts, etc., all have their particular spheres, and in many organisations doctors, lawyers, and

the seafaring professions also play their part. In Abadan here, even the humble rat-catcher does his little bit, but whether the Committee of this Institution would regard rat-catching as a suitable subject for a technological paper is, of course, another matter.

To give you some idea of the extent of the Industry I will briefly review the processes involved in obtaining oil and getting its products to the consumer.

When this world was formed, whoever was responsible for it ordained that Petroleum should be tucked away in pockets in the bowels of the earth, and the first important problem in the Industry is to find the oil. Usually the initial information consists of a rumour to the effect that a smell of oil or probably some seepages have been located in a certain district. In many cases, particularly in America, wild-catters rush to the scene and drill furiously to see who can reach the precious fluid first. The result is duplication and waste of effort with every probability of ruining the Field if there is one there, and in any case, if production is realised, a considerable waste of oil due to the incomplete arrangements for its storage and transport. The saner method, as practised by the larger Oil Companies, is to obtain some reasonable concession or base for the promised land, and then proceed to develop it in a rational and scientific manner. Firstly, a geological reconnaissance is arranged. By modern methods of studying the surface structure of the earth a geologist is enabled to obtain some idea of the disposition of the sub-surface strata. Recently also a new fraternity have arisen known as geophysicists. These investigators are not to be confused with the old "doodle bug" or divining rod exponents. They are true scientific experts, who have brought to bear, on the problem of finding out what is below the earth's crust, all the known physical laws of gravitational attraction, magnetic variation, electrical conductivity and the transmission of pressure waves through various elastic media. These geophysical methods have achieved a considerable degree of success in recent years, and together with more advanced geological knowledge, have raised the problem of searching for oil from a morass of uncertainty and guesswork to a more scientific and practical level. The very instruments used in geological and geophysical work, such as theodolites, microscopes, delicate gravitational balances, seismographs, etc., indicate to what extent science has entered into this problem. Further, when it is realised that an oil well may cost £20,000 to drill, plus, very often, many more thousands for roads, getting machinery into site, etc., it will be appreciated why it pays to spend considerable sums of money on the preliminary investigations, to determine whether it is worth drilling at all.

After a decision to drill is arrived at, the next people in the scene are drillers and engineers. The boring of a hole into the ground, often more than a mile deep, is no mean engineering proposition, and the problem has necessitated the best efforts of steel and machine manufacturers to produce an apparatus which will stand up to the severe stresses imposed upon it. The manufacture of casing itself is specialist work which has received considerable impetus from the Oil Industry. In Field development also mechanical, electrical, and civil engineers all play their part. There are workshops, water supply, electric power, roads and buildings, etc., to consider, and in each case the engineer has often to adapt ordinary standard practice to suit the peculiar conditions which pertain in an Oil Field.

When oil is found the problem of transporting it to the sea coast for refining or shipment has to be faced, and the usual method of pumping through long pipe-lines has brought to the surface many special engineering and other problems. The demand for high-pressure lapwelded or solid drawn steel pipe in sizes up to twenty inches diameter has created an industry in itself, and has led to the development of large steel and tube mills both in Europe and America. The problem of pumping a viscous fluid like oil has necessitated the special study of pipe-line flow, pump design, etc., and the difficulty of corrosion of pipe-lines is one which is still not completely solved.

After the pipe-line comes the more complicated problem of refining the crude petroleum. In a modern Oil Refinery the oil is boiled, and split up into its constituents. These are stirred up in treating plants, seasoned with chemicals, filtered and often boiled again to render them in a fit state to be served up on the breakfast table of the world to satisfy the voracious appetite of the automobile carburettor, the hungry maw of the boiler furnace, the rapacious demands of the ever-growing Diesel infant, and the delicate constitution of the more aged and frail kerosine lamp. The problems and processes involved in converting crude petroleum into products suitable for the market are so numerous and complex that time will not allow us to touch upon them this evening. The fact that it is possible to boil daily several million gallons of a highly inflammable liquid like petroleum, and then to handle its various products through several treating processes, with comparative immunity from fire and other risks, is, in itself, sufficient testimony to the degree of excellence which modern refinery plant has reached. In recent years the combined efforts of chemists, physicists and engineers have produced remarkable changes in refinery equipment, and a very special feature of such work is that progressive development is continuous, the tendency being the whole time

towards efficiency, simplicity, and safety in operation. The business of refining petroleum involves a knowledge of problems ranging from the study of the intricate molecular composition of organic substances to the construction of a 10,000-ton tank; from the thermal principles of distillation to the design and lay-out of large power and pumping plants; from the physical laws of gases to the development of huge stills capable of boiling nearly a million gallons of oil a day. No less varied are the actual products which can be made from petroleum. Fuel oil, kerosine or lamp oil, petrol, spirits for special purposes such as dry cleaning, paint thinning, etc., tar, pitches, coke, paraffin wax, lubricating oils, etc., are all derived from petroleum. Even chewing-gum is made from a crude oil product. In fact, it is stated that there are some 250 separate individual substances in actual use in the world all made from petroleum. Each of these products in itself forms a basis, or is intimately connected, with some other industry, so that the Petroleum Industry can be regarded as a large parent with many offspring. When one considers the number of motor-cars, steamships, Diesel ships, oil-engine power plants, etc., in the world, it becomes apparent to what extent the Petroleum Industry has had an effect on the progress of civilisation.

After refining comes the distribution of the products to the consumer, and on this question one cannot help but point to the development of the oil tanker in recent years. The transport by sea of large quantities of a highly inflammable liquid such as petrol is a problem which has required considerable co-operative effort on the part of the naval architect and the engineer. The extent to which the problem has been solved can be judged by the millions of tons of oil which have been carried overseas in the last few years with a negligible quota of accidents. Transport of oil by rail has produced the rail tank car, and by road the tank lorry. Last but not least is the never ending train of petroleum ramifications is the familiar roadside petrol pump.

I have endeavoured to point out to you the tremendous range of professional activity which the Petroleum Industry demands. Its technique varies from geology to naval architecture; from drilling to distribution; from geophysics to engineering; and from chemistry to accounting. The apparatus and plant used may vary from a high-powered microscope to a 2½-million gallon tank; from the most delicate chemical balance to a 10,000-ton ship; from a seismograph to a bench of stills; and from a roadside pump to a 1000-mile pipe-line. All these activities go to make up the comprehensive whole of the Industry we propose toasting this evening. Naturally, with so many branches, it is essentially an industry for specialists. None of us can really keep completely *au fait* with all

its phases, but one of the most important objects of this Institution is to enable its members to obtain at least some glimpses of what their colleagues' activities are.

Without entering into any controversial discussion on capital and labour problems, there is a second aspect of the Petroleum Industry I should like to mention—namely, that it is essentially an industry which can only be developed by the larger corporations. The initial capital outlay required even before a drop of oil is found is so great as a rule that the small operator does not stand a chance. The finding of oil even with a concentration of modern methods (and these on themselves are expensive) is still somewhat of a gamble, and even after oil is discovered, the capital outlay required for subsequent development and marketing is usually colossal. The Oil Industry is therefore, on account of its difficulties and complexities, pre-eminently one which depends on the capitalist for its development. The last feature of the Petroleum Industry which I should like to comment on is the intense interest which it has for the technologist. It never becomes stale. Every year there is some new development, some new problem to be tackled, some new markets to be catered for. The history of the growth of the Industry is one long story of a continuous struggle to provide for the more insistent, the more fastidious, and the ever-increasing demands of mankind.

In conclusion, we are proud to be associated with the Industry, and I therefore take this opportunity of asking you to toast its prosperity and advancement.

Mr. E. W. H. Peel, in replying to the toast, said: Mr. Chairman, Ladies and Gentlemen, it is my pleasant duty to thank you, Mr. Chairman, for the toast you have proposed, and you ladies and gentlemen for the way in which you have honoured it. The thanks of us are due to you, Sir, for the interesting speech to which we have just had the pleasure of listening. The task of replying is one which I approach with considerable awe, realising as I do how incapable I am of adequately expressing an idea so vast as the subject of this toast. The age of our Industry is perhaps not generally realised when thinking in terms of its recent expansion—an expansion with which in these parts, you, Sir, have been intimately connected. One of our earliest references to the Industry dated about the fifth century B.C. is contained in Herodotus, from which I will now quote a translation.

> "I myself saw pitch drawn from the water of a pool in Zante (an island off the west coast of Greece); into this pool they drop a pole with a myrtle branch made fast to its end and bring up pitch on the myrtle smelling like asphalt and for the rest better

than the pitch of Persia. They then pour it into a pit that they have dug near the pool, and when much is collected they fill their vessels."

Evidently even in those days there was active competition in the Near and Middle East; they were aware of certain technical difficulties with regard to Persia's products and had worked out a scheme for the production and distribution of their own. As far as Western civilisation is concerned, it must always be a source of satisfaction to us that a Scotchman, James Young, from his researches in Oil Shale in the middle of the last century was able to lay the foundations as we know them to-day. Shortly afterwards Colonel Drake drilled his sensational well at Titusville, Pennsylvania, and the flood of oil was let loose in America. The recent world-wide developments of the Petroleum Industry must be well known to all of us. With its products being increasingly used on land and sea and in the air, it needs no imagination for us to prophesy a still more glorious future.

"Our Guests."

Mr. G. W. R. Taylor, in proposing the toast, said: Ladies and Gentlemen, this toast is one that makes us realise to the full the ideals of good fellowship and hospitality. As Members of the Institution we meet as a family and we are, therefore, more than glad to have our guests come along and assist in our celebration this evening. Some of them, we hope, will be so influenced by the family spirit of the occasion as to join us presently under the same roof tree. We have with us representatives of practically every sphere of effort which goes to make up our business—Chemistry, Engineering, Commerce and others. Each branch has its own share of the work, which, combined, carries with it the advancement of the Industry and adds to the credit and prosperity of the Company to which we are proud to belong. Time does not permit of the separate mention of each of our guests, welcome though each one is, but I would especially express our pleasure at having with us Mr. Gass and Mr. Brewster. We have also with us two guests to whom we would extend a very hearty welcome—Dr. Hundsdorfer and Herr Suckau. Dr. Hundsdorfer and Herr Suckau are with us at Abadan for the purpose of giving us the benefit of their experience and advice on certain matters, and we hope their stay with us will be as enjoyable to them as I am sure it will be profitable to ourselves. Lastly, gentlemen, we have the Ladies who have honoured us with their presence. Here words fail me to indicate how much we are indebted to them—for their being with us this evening and for their being at Abadan at any

time. Gentlemen, I will ask you to assist me in showing the cordiality of our welcome by rising and drinking to "Our Guests," coupling with the toast the name of Mr. Gass.

In reply, **Mr. N. A. Gass** said: On behalf of the guests he expressed a very hearty vote of thanks to their hosts, coupled with the sincere wish that the Persian Branch would enjoy a long and uninterrupted period of prosperity to the inestimable benefit of the Industry it represented.

"The Institution of Petroleum Technologists and Chairman of the Persian Branch."

Mr. Brewster, in proposing the toast, said: Mr. Chairman, Ladies and Gentlemen, it has occurred to me that perhaps there is not, in the community of Abadan, anybody who has known the Chairman quite so long as myself. The Chairman's association with the Oil Industry is distinguished in that he has been connected with all the real up-to-date technical developments in both the fields and refineries. Turning to the Institution, it might not be generally known that it is still a very young organisation, having been formed in 1914 under the Presidency of that distinguished petroleum technologist, Sir Boverton Redwood. A perusal of the membership roll of the Institution shows remarkable growth, notwithstanding the set-back occasioned by the world war. It might at the moment be justly considered one of the most virile societies in the country. Amazing as its numerical growth has been, the increase in quality and quantity of published matter in the Journal of the Institution is even more remarkable. The quality of the contributions is second to none of the Foreign Petroleum Societies, which is saying a good deal when it is realised that England is not an oil-producing country, and all our experience of petroleum prospecting, production, transport, refining, etc., has been gained in foreign fields. Diverse and elaborate as the work on petroleum problems, as exemplified by the transaction of the Institution of Petroleum Technologists, indicate that there is a vast unexplored territory still ahead of the petroleum industry, and it is only by co-ordinating the work of the ever-increasing army of investigators that the present wide gulfs in our knowledge of petroleum in all its phases can be effectively breached. To mention a single phase which is often spoken of in the industry, namely, sulphur, will show that our knowledge of this unpleasant constituent of petroleum is very meagre and cryptic. The chemists know a little about these sulphur compounds, but what they do not know about them is a much larger item. However, patience and perseverance, together with systematic research, will undoubtedly solve the constitution of the petroleum sulphur com-

pounds and enable the refiner to eliminate from the finished products these alleged obnoxious bodies.

Some few years ago the refining of Persian benzine was regarded as something of a problem, but research proved that hypoclorite of lime and soda worked a wonderful change. In conclusion, I would like to congratulate you and your local branch of the Institution of Petroleum Technologists on the success of your first year's working. The papers read have covered a wide range of interesting subjects and have evoked really interesting discussions. There is, I believe, sufficient talent in Abadan to furnish a further series of papers, and I can see a busy season ahead of you. On behalf of those of us who have not yet joined your Institution, I think I may say without reservation that to-night's dinner has been an incentive to get busy and fill up an application form. We thank you for the opportunity of witnessing this interesting function to-night, and wish you and your Institution every success in the forthcoming session.

Mr. H. Y. V. Jackson, in replying, said: Ladies and Gentlemen,—On behalf of the Persian Branch of the Institution of Petroleum Technologists, I should like to express my appreciation of the sentiments expressed in the toast which has just been honoured, particularly as my own name was coupled with the Institution. I will confine my remarks to expressing a wish that many of our guests here to-night may become members of the Institution. One may possibly imagine that as most of us are connected with the Petroleum Industry, we would be so saturated with its technology that any further activities at the Institution meetings would be redundant. The Institution meetings however fill a recognised gap, and as I stated earlier in the evening, enable one to take a professional interest in other phases of the Oil Industry, which is sometimes not possible during the course of the daily round, and to discuss technological problems to their mutual interest and advantage. I would, therefore, recommend all of you who are connected with the Industry and are not already members of the Institution, to take steps to join. This Persian Branch is a very flourishing one, as can be seen from the following figures for membership:—

	1926.	1927.	1928.
Members	8	12	14
Associate Members ..	15	45	46
Associates	1	5	5
Students	3	3	4
Total	27	65	69

Its success is without doubt due to three factors : firstly, the support given by the parent Institution in London ; secondly, the assistance given by the Anglo-Persian Oil Co. ; and last but by no means least the tremendous amount of work put in by our energetic Secretary, Mr. Aylwin. I should like to mention that we have sent off a telegram to the Institution in London, who are also holding their annual dinner this evening, reading as follows :—" On occasion of First Annual Dinner, Persian Branch send good wishes to Parent Institution." In conclusion, Mr. Brewster, I thank you for your cordial toast.

The following cable in reply was received from the Parent Institution :—" President and Members at Annual Dinner much appreciate good wishes of Members Persian Branch and send cordial greetings on occasion of their First Annual Dinner."

INSTITUTION OF PETROLEUM TECHNOLOGISTS.

RUMANIAN BRANCH.

SECOND ANNUAL REPORT.

THE Committee have pleasure in presenting their second Annual Report for the year ending October 26, 1928, together with the accounts to that date.

REVENUE ACCOUNT FOR THE YEAR ENDING 26TH OCTOBER, 1928.

Receipts.

Dr.	£ s. d.	£ s. d.	*Lei.*
To Grants received from the Institution of Petroleum Technologists—London :—			
Monthly Grants—			
1927— 2 Grants at £2 each ..	4 0 0		
1928—10 Grants at £3 each ..	30 0 0		
		34 0 0	
Special Grants—			
Towards Deficit as at Oct. 17, 1927 (Lei 3,975.00)	5 0 0		
Towards Deficit on Annual Dinner (Lei 4,103.00)	5 5 0		
		10 5 0	
		44 5 0	35,023.00
Monthly Grants received in Advance, November and December, 1928, at £3 each		6 0 0	4,810.00
		50 5 0	39,833.00

Note.—Grants in Sterling have been converted into Lei at the rates of exchange ruling at the dates on which they were paid into the Private Sterling Account of the Treasurer.

Expenditure.

Cr.	*Lei.*	*Lei.*
By Balance of Cash on Hand as at October 16th, 1927		2,175.50
General Expenses :—		
Printing and Stationery	8,189.00	
Postages	4,037.50	
Expenses of Reporter at Meetings	6,000.00	
Miscellaneous Expenses	2,810.00	
	21,036.50	
Deficit on Annual Dinner held on December 2nd, 1927	7,490.00	
		28,526.50
Balance of Cash on Hand as at October 15th, 1928 ..		9,131.00
		39,833.00

We have verified the above Receipts and Payments Accounts with the Books, Records, Vouchers and other Documents of the Rumanian Branch of the Institution, and having obtained all the information and explanations we have required, we are of the opinion that such Account is properly drawn up to represent a true and correct Statement of the Receipts and Payments for the period under review.

(Signed) PRICE, WATERHOUSE & Co.

1, Bulevardul Domnitei,
Bucharest.

October 22nd, 1928.

The following is a list of Members showing in the Branch registers:—

Honorary Members	1
Members..	49
Associate Members	21
Students..	4
Associates	1
	76

This is an increase of 20 over the total membership of a year ago.

The average attendance of Members and Non-members at the meeting for the year was 49.

Five General Meetings of the Branch were held during the year ended October 28, 1928, and the following papers read and discussed:—

THE NINTH GENERAL MEETING AND FIRST ANNUAL GENERAL MEETING, October 28, 1927.

The Annual Report by the Committee was adopted.

Mr. Colin M. Leitch read abstracts from a paper, "Air and Gas Lift," by E. O. Bennett and K. C. Slater.

THE TENTH GENERAL MEETING, December 16, 1928.

"The Recovery of Gasoline from Field and Refinery Gases," by Ion Edeleanu, A.C.G.I., B.Sc. (Eng.), D.I.C.

THE ELEVENTH GENERAL MEETING, February 3, 1928.

"Efficiency of Back-pressure Methods in Meotic Wells of Moreni," by J. A. Chaillet.

THE TWELFTH GENERAL MEETING, March, 16, 1928.

"Certain Conditions Governing the Underground Relations of Oil, Gas and Water," by E. T. Hancock.

THE THIRTEENTH GENERAL MEETING, April 27, 1928.

Mr. Colin M. Leitch read extracts from a paper, "Portland Cement for Shutting off Water," by John F. Hough, Structural and Technical Bureau, Portland Cement Association, Chicago.

THE FIRST ANNUAL DINNER of the "Rumanian Branch" was held on December 2, 1927, at the "Clubul Industrial şi Internaţional," and was attended by 77 Members and their friends.

The Chair was taken by Mr. Arthur A. Ashworth in the absence of our Chairman from the country.

The Committee for the year were :—

Captain T. S. Masterson, D.S.O.
F. W. Penny.
Jacques Jaroslawici.
J. M. Walsh.
J. E. Treacy, *Honorary Secretary.*

Mr. Frank Russell was co-opted in Janaury to serve on the Committee in accordance with Article 3, Section E.

The Committee wish to thank the "Clubul Industrial International" for the use of the Club for the meetings and also wish to express their appreciation and thanks to Mr. R. W. Davison and Colin M. Leitch for the services rendered, and Messrs. Price, Waterhouse & Co. for acting as Honorary Auditors.

By order of the Committee.

J. E. Treacy,
Hon. Secretary.

INSTITUTION OF PETROLEUM TECHNOLOGISTS.

RUMANIAN BRANCH.

THE FOURTEENTH GENERAL MEETING of the Rumanian Branch of the Institution of Petroleum Technologists was held on October 26, 1928. The Chair was taken by Captain J. E. Treacy, and the following paper was read :—

Gas Lift Operations in the Seminole Oil Field.

By S. F. SHAW.

THE Seminole oilfield was discovered in the spring of 1926 by a well drilled into the Hunton formation. During the summer of the same year the Wilcox formation was found to be oil-bearing, and within a few months large wells of 3,000 to 10,000 barrels were being brought in almost daily from this formation. The peak of production was reached in July, 1927, when a production of slightly more than 525,000 barrels was made. Total production of the Seminole field to date is probably close to a quarter of a billion barrels. One of the companies has produced approximately 30,000,000 barrels, of which 19,000,000 were produced by gas lifts.

The Wilcox sand of the Ordovician System averages about 25 ft. in thickness so far as the pay section of the oil-sand is concerned. Deeper drilling frequently brought in bottom water. The sand is well consolidated, and no trouble is encountered with sand running into the well and choking the flow. Wells are usually shot with nitro-glycerine ; sometimes they are shot several times, and in many cases large increases of production have resulted.

The wells are from 4000 ft. to 4500 ft. in depth and spaced 660 ft. apart. They are usually finished with a 6-5/8 in. casing, 26 lb. weight, and in some cases with casing of 5-3/16 in, 17 lb., and in a very few cases with casing of 4-3/4 in. diameter. When gas lifts are employed in the early stages, the well is provided with upset tubing of 2½ in., where the casing is 6-5/8 in., and with tubing 2 in. diameter where the casing is 5-3/16 in., and the oil is flowed through the annular space between the casing and the tubing.

The oil is about 41° Baume, or about 0·82 specific gravity. There are no paraffin troubles with which to contend. In the later life of many of the wells encroachment of edgewater takes

place, and production declines very rapidly thereafter. There is a certain amount of hydrogen sulphide gas present, and as soon as the water makes its appearance corrosion troubles become serious. In wells that are flowed by air, corrosion of tubing and casing proceeds rapidly. This trouble is less pronounced where gas is employed instead of air. When employing tapered tubing in which the design was such that the lowest section in the well accommodated a given production, corrosion in the interior of the lowest section reduced the section such that large losses in production occurred. In one case it was found that the opening within a 2½ in. tubing was reduced to about one-half of an inch in diameter and the production dropped from 100 barrels to 10 barrels per day. Experiments are now under way in this field in which tubing made of various kinds of metal is being employed with the hope of ameliorating this condition.

The rock pressure in new sections may reach 1000 to 1200 lbs. per square inch, while in new wells in older sections of the field the rock pressure may be as low as 200 lbs. per square inch. The pressure drops rapidly, and in a few months the flowing pressure is usually down to 100 to 150 lbs. at the bottom of the well. Gas-oil ratios are low; in the main section of the field the gas-oil ratio probably averaged about 500 cubic feet per barrel. In the new South Little River section the gas-oil ratio has been about 400 cubic feet per barrel when the wells are first drilled. The average gas-oil ratio for wells about a year old has been about 1000 cubic feet per barrel, though in several cases the gas-oil ratio has declined rather than increased. This may be due to the approach of edgewater. The low pressures and gas-oil ratios result in flowing wells being very sensitive to any changes; wells flowing 3000 barrels per day have ceased to flow when a string of tools or a string of 2½ in. tubing was being lowered into the hole. Back pressures of 10 to 50 lbs. per square inch have stopped the flow entirely. One well with initial production of 4000 barrels had declined to 3100 barrels, when it was found that a back pressure of about 20 lbs. existed. A separator was placed close to the well and all angles possible to eliminate were removed, after which the production increased to 7000 barrels per day.

Use of the Air-Gas Lift.—The first air-lift work in the Seminole district was done in October, 1926, but the initial results were not very satisfactory. Within a few months, however, conditions in the field had become better known, and by the summer of 1927 probably between 50 and 75 per cent. of the total production was made by air- and gas-lifts. Air was employed at first as the lifting medium, owing to the greater ease in installing equipment, but it

soon became evident that a large quantity of gasoline could be recovered by employing gas. At the present time in the Seminole district there is probably more than three-quarters of a million gallons of gasoline per day being made, most of which is derived from recycling operations. As soon as water made its appearance with the oil another reason for changing from air to gas was found, in order that corrosion troubles might be reduced to a minimum. There seemed to be no difference of consequence in the action of compressed air and compressed gas in the lifting of the oil.

In the early operations not much attention was paid to the position of the separator, and the use of many elbows and tees in the flow line was the rule. Later, more attention was given to this subject with notable increases in production. Practically all of the types of compressors possible to find were employed, including compressors belted to gas engines and to electric motors, and compressors direct driven by gas engines and steam engines. The separators were placed close to the wells; gas lines of 3 in. diameter from the compressors to the wells were adopted by some of the companies in order to reduce the friction loss in the line to a minimum. Tubing of 2 in. and 2½ in. was employed in the wells in the early stages, which was followed by tapered tubing by one or two companies when the wells had declined to 300 or 400 barrels per day.

When the gas-lift was first employed in a well the consumption of input gas varied from 500 to 1000 cubic feet per barrel of oil lifted. When production had declined to 300 to 400 barrels per day, it was found necessary to use about 2500 cubic feet of input gas per barrel where tapered tubing was employed. Intermittent flowing of wells producing from 10 to 25 barrels per day, at intervals of one hour to three hours, required from 5000 to 6000 cubic feet of input gas per barrel.

As a result of the experiences at Seminole, the writer is of the opinion that in fields where conditions are similar, and where the utmost is demanded in continuity of service, the belted compressor driven by electric motors is preferable where electric power can be obtained at a reasonable price. After the pressures and production have declined considerably, to perhaps 500 or 1000 barrels per day, it appears advisable in the interest of economy to change the electric motor to a gas engine.

Cost of Lifting by Gas Lift.—The cost of compressing gas per 1000 cubic feet by electric motor, when pressures range from 300 to 400 lbs. per square inch, was found to be about 7½ to 8 cents per 1000. Compressing at 100 to 150 lbs. resulted in a cost of 5 to 6 cents per 1000 cubic feet. Two-stage compression in direct driven gas engine compressors was about 4 cents per 1000, while

single-stage compression cost in the neighbourhood of 2½ cents per 1000 cubic feet.

The lifting cost per barrel in wells where conditions obtained similar to those enumerated as above, would then be approximately as follows :—

Cost per M cubic feet at	8	5	4	2½
	cents per barrel lifted.			
At 500 cubic feet per barrel ..	4 ..	2½ ..	2 ..	1¼
At 1,000 ,, ,, ..	8 ..	5 ..	4 ..	2½
At 2,500 ,, ,, ..	20 ..	12½ ..	10 ..	6¼
At 5,000 ,, ,, ..	40 ..	25 ..	20 ..	12½
At 6,000 ,, ,, ..	48 ..	30 ..	24 ..	15

Single-stage compression can be employed only in wells where the flowing pressure is low, and where the friction loss in the line to the well and in the line down into the well is held down to a low point. Deep wells require most careful attention in pipe design to achieve this object.

Periodic Testing of Wells.—It has developed that the periodic testing of wells being flowed by air or gas lifts is of considerable importance, consequently it was found desirable to train a number of engineers for this work and assign to each man a certain number of wells for which he was to be held responsible. Thorough tests are made at intervals of a week to a month, depending upon the age of the well and upon the rapidity of decline in production. In a well that has been holding a fairly steady production there is no necessity of making tests more frequently than once a month. Practically all wells so handled are provided with input and output orifice meters and with separators close to the well. The gas is measured by means of the orifice meters while the oil is measured in the separator if the flow is not too great, and in the stock tanks if the flow is in excess of 1500 barrels per day.

The data applying to the wells which are required in connection with the making of tests are as follows :—

Depth of the well.
Length and diameter of the oil string.
Length and diameter of liner and where the liner is set.
Length and diameter of the tubing.

When a test is made the following observations are noted :—

Quantity of oil per unit of time, and specific gravity of the oil.
Quantity per unit of time, specific gravity and temperatures of input gas.
Quantity per unit of time, specific gravity and temperature of output gas.

These observations having been noted and calculations made, it is possible to calculate the following data :—

Quantity of gas accompanying the oil from the sand or formation,
Quantity of input gas per barrel of oil.
Quantity of output gas per barrel of oil.

Quantity of gas with the oil, or in other words, the gas-oil ratio.
Pressure at the bottom of the well, or at the lower end of the tubing.
Submergence in feet of oil, and the percentage of submergence.
Lift in feet to which the oil must be raised.
Quantity of gas required to lift one barrel for the given submergence and lift (from formula or table).
Percentage of efficiency in lifting the oil.
Quantity of fluid per unit of time at the lower end of the tubing.
Quantity of fluid per unit of time at the top of the tubing.

Several tests are made at a given well by varying the operating conditions during the course of the day and calculations made for each of these conditions. With the data so obtained the engineer is in a position to determine the most efficient and most economical rate of producing the well. He can determine whether the tubing is too small or too large, whether the tubing or casing through which the oil is lifted, as the case may be, is the proper size for the production that is being made or could be made. If the oil is being lifted through the annular space between the casing and tubing it is not often that the casing can be changed to obtain a larger flow; but in the event that the casing is too large for the production that is being obtained, it is possible to employ a size of tubing that is of the proper size through which to lift the oil. It has been found that tapered tubing gives a higher efficiency than straight tubing, but conditions may make it inadvisable to employ tapered tubing. Designs of tapered tubing are only possible after the engineer has had extensive experience in gas lift works, which prevents a general use of this method. Corrosion troubles, loose unconsolidated sand, and paraffin deposition all may interfere to such an extent as to make the use of tapered tubing impracticable. Whatever be the type of tubing lowered into the well, it would probably be advisable to pull the tubing every few months for the purpose of making inspection.

It has been found to be beneficial to make periodic tests of the compressors employed and determine the volumetric efficiency. It is not difficult for rings and pistons to become gradually worn in a few months to a point where the output is reduced from 20 to 30 per cent. below that possible to obtain. This loss may take place so gradually as to be unnoticed. This reduction in the quantity of gas supplied to the well might result in a serious loss of production.

The most efficient manner in which to produce the oil in a given field can be determined only by trial, taking into consideration all of the conditions that obtain. The question of gas-oil ratios is one being freely discussed at the present time, and while every effort should be made to reduce this ratio to a practicable minimum, it should be said that no iron-clad law has been discovered that

will govern this ratio in all fields. As engineers we should also bear in mind that profits cannot be sacrificed to too great an extent to secure low gas-oil ratios.

Various problems have arisen in connection with gas-lift operations, some of which are dependent on laws and experiments not yet thoroughly worked out. For instance, in computing the pressures at the bottom of long strings of tubing, by means of friction formulæ, various inconsistencies were noted. In order to ascertain the reason for these inconsistent observations a string of 2½ in. tubing 4000 ft. in length was laid out on the surface and varying volumes of air and gas were passed through the line, ranging from 150 to 1400 cubic feet per minute, with discharge pressures varying from atmospheric pressure to 200 lbs. per square inch. Orifice meters were placed on both the input and discharge ends of the line. It was found that for high velocities, especially where the discharge pressure was low, the usual friction formulæ are not applicable. It was also noted that where temperatures varied widely the orifice meters gave inconsistent results, but so far we have not had the opportunity to definitely ascertain the reason for these inconsistencies in orifice meter measurements.

Gas-Lift Operations in the South Little River Section of the Seminole Field.—The newest section of the Seminole district to be opened to production is the South Little River pool, which was opened to maximum capacity on September 10th, 1928. Compressor displacement capacity in excess of 100,000,000 cubic feet per day has been installed, of which one company had installed capacity in excess of 30,000,000 cubic feet per day. The unrestricted production started at 129,000 barrels per day.

Based on the experience gained in the older sections of the Seminole field, several compressor plants were installed in the South Little River field containing from six to sixteen electric motor-driven compressors, each with displacement of approximately 250,000 cubic feet per day per compressor. The intake gas passes through a simple tank as a scrubber, thence to the compressor. Each compressor was provided with individual intercooler, and the gas line to each well was passed through an aftercooler, thence to the well. The discharge from the well goes to a separator set up close to the well, whence the oil gravitates to the oil stock tanks, and the gas is returned through the recycle line to the scrubber and to the compressors. A bank of input meters was set up close to the compressor plant, one for each well, and the operators are instructed to inspect the meters from time to time in order that they may discover if anything out of the ordinary is taking place. An output meter is placed on the line from the separator of each well

in order that the production of gas from the well may be known. The cooling water through the intercoolers and aftercoolers is maintained at a temperature that will condense the proper quantity of gasoline, which in South Little River section started off at a ratio of two gallons of gasoline per barrel of oil. The value of the gasoline at the present time is considerably in excess of the lifting costs.

Sufficient observations have not been made yet that would enable me to comment on the practicability of employing air-gas lifts in the Rumanian oilfields. The conditions are quite different from those in fields of the United States, where the gas lift has seen its widest application, particularly as regards the effect of fine unconsolidated sand and the large quantity of paraffin found in some of the Rumanian fields. Whether these difficulties can be overcome to such extent as to permit the general use of the air-gas lift remains to be determined.

DISCUSSION.

In the course of the discussion Mr. J. A. CHAILLET suggested that tapered tubing would be practical where the oil was paraffinous, as by its use the velocity was diminished, thus reducing the expansion and so maintaining the temperature and preventing waxing up.

Mr. G. ELIAS asked if the use of dry gas instead of wet gas did not cause a loss in gravity of the oil, owing to the gas taking up gasoline from the crude.

Mr. J. T. HAYWARD asked if the surface of the tubing and the type of joint had any effect on the results.

Messrs. J. M. WALSH, T. P. PERROTT, H. S. VIRGO and Mr. COWAN also took part in the discussion.

The author, in reply, said that, with 8 or 10 in. casing, tapered tubing can be employed with advantage, and also in extreme cases in smaller sizes of casing. The gravity of the crude oil is nearly always lowered by the use of gas; in the case of high gravity oils by 3° to 4° Bé. The condition of the interior surface of the flow string largely affects the efficiency of the air-lift. As regards joints, tubing tapered out from bottom to top is the best arrangement.

INSTITUTION OF PETROLEUM TECHNOLOGISTS.

RUMANIAN BRANCH.

SECOND ANNUAL DINNER.

THE Second Annual Dinner of the Rumanian Branch of the Institution of Petroleum Technologists was held at the Industrial International Club, Ploesti, on Friday, November 30, 1928. Captain J. E. Treacy occupied the chair.

"The Petroleum Industry of Rumania."

Mr. F. W. Penny, in proposing the toast of "The Petroleum Industry of Rumania," said: The oil industry is now so knit together and sensitive that outstanding events in one section of it are reflected throughout the industry; for example, abundance and rapidity of transport cause an over-production in one area to affect every area. In other words, the whole industry enjoys a boom or experiences a slump together.

There can be no doubt that our greatest present-day problem is to keep production within reasonable bounds: though over-production is at present obvious only in America, it has adversely affected the prosperity of the industry all over the world, including Rumania. An interesting question is, how continued or increasing over-production will affect Rumania, and if any steps will need to be taken here to counteract it.

The conditions of the petroleum industry in Rumania and in the U.S.A. have some points in common; for example, production is divided between a relatively few large companies and a large number of independent small producers, the former having most of the profitable flush production and the latter most of the settled production.

In a period of depressed prices, the small producer of settled production will have to go out of business long before the others are seriously affected. As he is the backbone and stabilising force of the industry, that would be most undesirable; and so measures have had to be taken there to prevent the price structure from becoming too depressed. As the largest wells are the lowest-cost producers, low prices do not at once retard production, and

so the measures which have so far been taken are restrictions or pro-rationing of production.

On the other hand, in the young oil countries the production is mostly flush and the small independent producer is insignificant, so that restriction is not yet an urgent question.

Restriction of production has been practised in California for several years, and in Oklahoma for several months. Its history has been an ever-widening circle. It started as a private arrangement among companies in one field, and now is enforced by the State Legislatures in Oklahoma, Texas and Kansas, and an attempt is already being made to extend its scope outside the U.S.A. The question which is being asked is: why should production in the U.S.A. be restricted while South America and other areas are wide open?

Will this ever-widening circle reach Rumania? For the purposes of world production, Rumania can be considered as one field. Less than a third of its present production can be absorbed in the country, the rest being exported. At present it is *not* a critica factor, mainly because it can handle and market its current production. There is no large reserve of stored crude or products waiting to be thrown on to the world market at a favourable opportunity, as in other countries. Further, the production can only increase fairly slowly, being limited to transportation facilities; and such a slow increase is at present taken care of by the slowly increasing consumption of its markets.

The *natural* market for Rumanian products is the countries bordering on the Danube as far as South Germany. When, due to increase of production, that market is saturated, then the Rumanian producer will more and more have to penetrate into his second market, i.e., the countries bordering on the Mediterranean, where he comes into more severe competition with other producers. A pipe-line is projected from the Persia-Irak area to the Mediterranean seaboard, which will bring another competitor into this market. The other nearby competitor is Russia.

What then are the prospects for the future? The causes of the excess of production in the U.S.A. were the increased activity of the wildcatter coupled with the effectiveness of geological work, which caused the discovery of one large flush pool after the other all over the country; secondly, the increased efficiency of the methods of producing the oil; and thirdly, the financial facilities which enabled huge tank farms and pipe-line schemes to be undertaken. As the prices went down, the engineers devised better and cheaper methods of production to enable their company to still make a profit.

The same thing has started in Rumania, owing to the exchange of experts between the two countries. Recent advances in drilling equipment and technique has enabled the old fields to be developed in depth as well as in area; an oil source at 1500 metres now has no terrors for the modern field man, and the introduction of the airlift has made every new well a flowing well. A mere recital of the areas where folded Meotic will be within reach of the modern drill as soon as the land is made available is imposing. Thus, the production of Rumania looks as though it will go on increasing, transportation facilities will be improved, its natural market will become saturated and oil may have to be stored above ground. Although it is realised by individual producers that the best place to store oil is in the ground, production—owing to the necessity of protecting one's leases from drainage—is one of the things which cannot be checked, except by mutual agreement.

In the Mid-Continent field of America developments round wild-cat wells are controlled and fields with an average production of more than 100 barrels (1½ cars) per well per day are pro-rationed to a stated total production. In this country, Ceptura, Gura Ocnitei, Moreni and Ochiuri would come into this category. These measures are in many ways a blessing in disguise; for example, the artificial reduction in production of the larger wells puts a back-pressure on the sands which eventually ensures a greater ultimate yield: the drilling of fewer wells per unit area saves capital expenditure and ultimately gets out the same quantity of oil. The main effect in both cases is to get production more slowly.

It is to be hoped that Rumania will benefit by the experience of the U.S.A., and by a timely regulation will not increase its production and transportation and storage to a point where its stocks cannot be taken care of. The present great activity is stimulated by the idea that, even at low prices, profits can still be made if production and throughput are sufficiently increased. But there is obviously a limit to this, which will be reached as soon as the absorbtive capacity of the possible markets is reached. When that point is attained, it may be difficult to rectify the situation by the obvious method of an international agreement with neighbouring producers for conserving production. On the one hand, in this country the government is by far the largest royalty-holder, which would facilitate the course of any such negotiations; but on the other hand, Russia has indicated that it will have nothing to do with any such scheme and will probably maintain that attitude as long as it can. With Russia outside the community of the world oil interests, no benefit could accrue to Rumania from any international agreement.

Therefore the Rumanian producer would probably have to turn to other means of relief. So far as concerns the mere business of producing oil products for less than their sale price, the Rumanian producer should not need to be in any precarious position. There is still some room for him to further reduce his cost of production and increase his profits by adopting methods and equipment in field and refinery designed for that purpose. But there is a limiting factor to this, because the investing of further capital for the purpose of lowering production costs will result in the loss of considerable amounts of capital previously invested, which can only be faced by companies with good financial backing.

If, before these stages are reached, the Rumanian producer finds himself unable to fulfil his primary function of making profits for shareholders, then it will probably be due to extraneous causes, such as too high royalties which were fixed during a period of greater prosperity, or excessive taxation. He will then have to either bring his production down to the capacity of his natural market, or these extraneous causes will have to be modified.

From this brief review one realises that there are difficult times ahead for the petroleum industry, and every branch of it in every country will have to adapt itself to the changing conditions. May the Rumanian industry weather the storm, which I think it should be in a good position to do, and fit itself in with the rest of the petroleum industry on a profitable basis, upon which the prosperity of all of us largely depends.

This toast is coupled with the name of Dr. I. Edeleanu, who has recently been elected to a place on our committee. I therefore have much pleasure in asking you to rise and drink with me the toast of "The Petroleum Industry of Rumania," coupled with the name of Dr. Edeleanu.

Dr. Ion Edeleanu, in reply, said: Apprehensions for the future of the oil industry are now quite frequent, but too much emphasising of these apprehensions creates an exaggerated feeling of depression which has not always corresponded to the actual situation.

Production in 1922 in Rumania was only slightly above one million tons, whereas this year the production is four times as much. While production is a knife with two edges, it is nevertheless a proof of the vitality of our industry. By perfecting the technical methods in the industry, we will lower the cost of production and increase the yield of valuable derivatives. The Rumanian oil industry will keep pace with progress and we can look with confidence to its future development.

"Our Guests."

Mr. J. M. Walsh said: We have with us to-night Engineer M. R. Andreescu, of the Department of Mines; Mr. Gage, the representative of our honorary auditors, and Mr. E. T. Hancock are also with us. We are pleased also to see a member from London, Mr. Chittenden. I therefore ask you to drink the health of our guests, coupled with the name of Engineer M. R. Andreescu.

Engineer M. R. Andreescu, in responding, said: We appreciate the honour of participating at an assembly of this Institution, not only from the point of view of the feelings which I believe we all bear to it, but also because of the special qualifications of the participants. Indeed, there are few associations whose members combine so many excellent qualities and to such a high degree.

It is certain that such an association will, by its supplementary qualities, spirit of co-operation, discipline and power, be a factor in ethical progress and, as a consequence of the results obtained, be a factor towards material progress.

For those reasons, gentlemen, your guests of this evening are very grateful for the hospitality extended to them. They raise their glasses and drink to the prosperity of the Rumanian Branch of the Institution of Petroleum Technologists, and wish health and long life to the members of the Institution.

"The Rumanian Branch of the Institution of Petroleum Technologists."

Mr. Eugen T. Hancock, in proposing the toast, said: The Rumanian Branch of your Institution is very essential in a region like this where oil is being produced and refined, and the valuable purpose which it serves is greatly augmented because of the fact that the meetings are held at Ploesti, which is centrally located with respect to the different fields. The drillers, field superintendents and engineers are able to meet with those who have to deal with problems pertaining to geology, production and refining, and through the mingling of ideas the entire petroleum industry is greatly benefitted.

The universal interest that has been shown in papers of a purely technical nature shows that the workers along various lines appreciate the fact that, in order to fully understand their own work, they must better understand the allied subjects. For example, the drillers and field superintendents are much more efficient if they understand the fundamental principles of stratigraphy and structure, and certainly the geologist is much more efficient if he is well informed on the technology of drilling and producing. Furthermore, geologists are much better able to solve the problems

pertaining to the origin of oil and gas if they understand the basic principles of refining, and the refiner, because the knowledge which the latter possesses with respect to the composition and behaviour of the various crudes under different chemical and physical conditions, is able to greatly assist the geologist and engineer, if he fully appreciates the problems which they are trying to solve.

It is very difficult to find a region where there is greater need of full and free discussion of the problems encountered than in Rumania to-day. The day of cheap production from the Dacic beds is passed. With the exception of a few possible localities, which do not look too promising, the exploitation in the future will be in the deep Meotic sands, and it is almost impossible to find another region in the entire world where more difficult problems are presented in one well than in Rumania. In regions where the formation is hard and where it is possible to carry a long string of casing from the surface, and especially where the natural gas pressure is low, drilling is not so difficult; but here the formation is soft and unconsolidated and in many instances the deep Meotic beds are overlain at or near the surface by the Dacic formation, the oil sands of which need protection. Furthermore, the strings have to be cemented and in order to insure circulation there is, of necessity, a rapid reduction in diameter of the casing. Finally, when the wells have reached depths often amounting to 1500 metres, they have to be cored in order to locate the top of the Meotic and suitable casing seats as well as oil sands and possible water sands. But that is not all. In coring for these horizons, sands are sometimes encountered the natural gas pressure of which amounts to from 2000 to 3000 lb. per sq. in. where it is necessary to circulate with a mud-barite-hematite solution, the specific gravity of which is sometimes as high as 1·9 and from which the barite and hematite settle out in the bottom of the hole so rapidly that it is almost impossible to take a core without getting about 90 per cent. of these substances. Imagine, if you will, trying to satisfactorily explore the Meotic beds through a 5 or 6 in. hole under those conditions. The operating companies are going to require every possible assistance if Meotic exploitation is to be a success.

I mention these facts because in proposing this toast to the Rumanian Branch of the Institution of Petroleum Technologists, I wish to emphasise not only the good purpose that this organisation has served since it was instituted, but also how important the organisation is bound to be in future years in furnishing an opportunity for a full and free discussion of the problems which will confront the petroleum industry in Rumania.

Captain J. E. Treacy, in reply, said: A very important thing in the oil industry appears to me to be the exchange of ideas. A short time back most companies were loath to divulge information pertaining to new methods. To-day they are glad to exchange ideas, as it is realised that they invariably receive as much as they are able to give in return. Coming to technical institutions, it will be noted with interest that the formation of branches is the natural outcome of their growth, and I am glad to say that our Institution is not behindhand.

Speaking of our own Branch of the Institution of Petroleum Technologists, we have so far had wonderful support from members and friends. In order that the good work may continue, we ask that you give us renewed support by coming forward with papers and taking part in discussion at our meetings. In this way we help our Institution to be of world-wide value, and our meetings to be the means of bringing the oil operators together in a spirit of goodwill.

INSTITUTION OF PETROLEUM TECHNOLOGISTS.

TRINIDAD BRANCH.

THE SECOND ORDINARY MEETING of the Trinidad Branch of the Institution of Petroleum Technologists was held at the Club House of the Trinidad Leaseholds, Ltd., at Forest Reserve, Fyzabad, on Wednesday evening, March 28, 1928. Mr. A. Frank Dabell, M.I.Mech.E., Chairman, presided.

The following is a précis of the paper read.

CEMENTING.

By F. J. SHAVER.

For the efficient exclusion of water from oil wells it is better to place an impervious bond between casing and the wall of the hole than to rely upon a formation shut-off, and cement is the best medium for such purpose.

Whilst the best water cement ratio gave a mixture too thick for pumps to handle, a satisfactory grout could be obtained by mixture of 0.6 to 0.7 cu. ft. of water with 100 lbs. of cement.

Accelerators used for hastening the setting of cement should first be tested in trial batches of grout in a manner that approximate the actual conditions in the hole, and when used in practice chemical accelerators should be first mixed with the water in the supply tank.

There was no advantage in the use of cements with a high tensile or compressed strength—importance lies in the use of cement of an impervious nature.

Cementing failures were most often due to the action of gas, for the prevention of which the running of the casing through a blow-out preventer, permitting the well to be closed after the operation of cementing be completed, was advised.

For shutting-off bottom water it is good practice to shoot the hole in a body of shale above the water sand and run cement into the cavity.

Attention was called to the fact that cement will set in salt water and oil and that the time of setting is reduced under the increased temperature due to depth.

Summarising, all cementing processes depend for their success upon the following five fundamental requisites ;—

1. A body of impervious shale at least 20 ft. in thickness opposite which the shut-off is to be made.

2. Careful measurements of hole and casing.

3. The effective preparation of the hole to receive the grout.

4. Thorough mixing of cement grout in the smallest proportion of water that will give the necessary fluidity.

5. The selection of a method of depositing the grout that will ensure its placement in an unadulterated mass at the location desired in the least possible time.

A discussion followed in which the following took part :—Messrs. A. Frank Dabell, J. S. Parker, T. W. Dagg, W. G. Payne, G. H. Scott, W. G. C. Tomalin, B. M. Craig, H. D. Fletcher, W. G. Bushe, H. W. Reid and J. L. Harris.

INSTITUTION OF PETROLEUM TECHNOLOGISTS.

TRINIDAD BRANCH.

THE THIRD ORDINARY MEETING of the Trinidad Branch of the Institution of Petroleum Technologists was held at the Club House of the Trinidad Leaseholds, Ltd., at Forest Reserve, Fyzabad, on Wednesday evening, April 25, 1928. Mr. A. Frank Dabell, M.I.Mech.E., Chairman, presided.

The following is a précis of the paper read.

RECOVERY OF OIL BY AIR AND GAS LIFT.

By W. G. PAYNE.

In this paper the generally-accepted views on air-gas lift were introduced. The opinion was expressed that the contradictory results described by different exponents were due to the widely differing oil-field conditions which called for departure from conventional practice. Reference was made to the refractory nature of certain emulsions formed in some fields where water is present and to the expense of breaking them down. The author stressed the need for exhaustive experiments on representative wells before expressing a final opinion regarding the value of gas-lift in any particular area. In any case the local conditions should be carefully studied before deciding upon the method of applying the process. The value of meters for measuring in-take and out-take gas volumes was also emphasized. Definite views in favour of gas were expressed owing to the possible deleterious effect of air on equipment and oil as well as dilution of gas possibly destined for gasoline extraction.

Within the author's experience overall efficiencies of air-gas lifts varied from 10 per cent. to 25 per cent. in well-arranged wells falling at times to 2 per cent. to 3 per cent. under unfavourable conditions. Tests made by the author in the El Dorado field of Kansas, where pumping by electrical power was in force, only gave overall efficiencies of 5 to 15 per cent.

CORRESPONDENCE.

Odsey,

Ashwell, Baldock, Herts.

Sir,—In Mr. Cunningham Craig's review of "The Geology of Petroleum and Natural Gas," on page 861 of No. 71 of the Journal, the last paragraph reads: "It is hardly fair to the pioneers of geo-physical exploration work in Europe to state, as is done on page 495, that "The reputation of both the seismograph and the torsion balance as tools for exploration for oil rest solely at the present time upon their success in the Gulf Coast territory of Texas and Louisiana." Years before either seismograph or torsion balance were used for geological exploration work in America, oilfields had been discovered and proved with the help of the torsion balance in Central Europe."

I regret to say that, to the best of my knowledge, no oilfields have yet been discovered by the torsion balance in Central Europe.

The pioneers of geo-physics in Central Europe came to the conclusion, from theoretical considerations, that certain oil structures could be discovered by the help of the torsion balance, and by their experimental surveys over known structures showed that these conclusions were correct, but it was left to the Americans to put this knowledge to practical use. W. H. FORDHAM.

Abbey Buildings,

8, Princes Street,

Westminster, S.W. 1.

Sir,—I must refer Mr. Fordham to a short article upon "Geo-physical Surveys as Aids to the Geologist," which I wrote for an American technical journal about the end of 1923 or the beginning of 1924. I mentioned Texas and Louisiana as specially favourable fields. The article was afterwards republished in this Journal (Vol. 10, No. 46).

Geo-physical methods such as the Torsion Balance and the Seismograph are after all only used for discovering concreted *structures*, not necessarily for the finding of *oil*. A magnetic method, however, can be used to give indications of the presence of petroleum.

Great credit is due to those who have so successfully utilised the Torsion Balance in Texas and Louisiana, but the value of that instrument had been demonstrated in Europe some years before, while at least one magnetic method had also been used with successful results. E. H. CUNNINGHAM CRAIG.

REVIEWS.

THE VISCOSITY OF LIQUIDS. By Emil Hatschek. London: George Bell and Sons, Ltd. Pp. 238, vi.

The author is one of the best known colloid chemists in the country, and therefore any work from his pen is worthy of the most careful attention. The present monograph in every way upholds his reputation. There have been two previous works on this subject, one by Dunstan and Thole and one by Bingham. Hatschek, however, covers a wider field and brings the subject up-to-date. The reviewer's earliest scientific work dealt with the relationships existing between viscosity and chemical constitution, and it has been a pleasureful occupation to go over the ground again in the light of more recent work and to find so little that needs correction or revision.

Hatschek's treatise discusses—inter alia—the fundamental concepts and historical development of viscosity, laying stress on the remarkable pioneer work of Poisseule, the mathematical theory of the principal method of determining the co-efficient of viscosity, the design and use of viscometers, the constancy of the co-efficient, the variation of viscosity with temperature and with pressure, the relation between chemical constitution and viscosity, the viscosity of solutions and of liquid mixtures, the relation between viscosity and conductivity, and the viscosity of colloidal solutions.

The work is so thoroughly and completely good that it is difficult to find any point to criticise—the reviewer would suggest that perhaps too much space is given to the discussion of empirical fluidity formulæ.

The book is admirably printed and produced, and the line diagrams are clear and informative.

A. E. DUNSTAN.

ELEMENTS OF GEOPHYSICS. By Dr. R. Ambronn. English Edition, translated from the German by Margaret C. Cobb, M.A., Ph.D. London: McGraw-Hill Publishing Co. 25s.

To those people interested in the subject of applied geophysics this book is not only comprehensive but covers the whole subject of applied geophysics on broad technical lines. This renders the book at once a work of science and of the utmost use for purposes of reference.

To assemble such a lot of useful data and to deal with each branch of geophysics—namely, gravimetric, magnetic, electrical, radio activity, thermal gradients, etc.—in such an effective manner must have occupied Dr. Ambronn for a considerable time.

The translation by Margaret C. Cobb, M.A., Ph.D., has been extremely well done, and the mathematical formulæ, carefully printed, without any apparent mistakes.

To the reader who purchases this book, due allowance must be made for what might appear disappointing discontinuities, as, for instance, under the heading of Radio Actiyity mention is made of a method of detecting the reaction due to oil, whereas it has not been made clear whether there is any reaction to detect. If this is so it is extremely interesting, and one would like to read more in Dr. Ambronn's book itself about the matter than being referred to another publication to follow it up.

Also, in the present state of the science, it is hardly safe for the author to dogmatise and say oil may or may not be detected direct under certain conditions, as the writer is aware of possibilities in this direction connected with seismographical methods, whilst at the same time as regards electrical methods the mathematical treatment is so profound, without the necessary data to calculate results, that it is hard to say what actually one does register when no standard of reference under similar conditions is readily available.

I am glad to see that Dr. Ambronn has not voiced the usual remarks, so often seen in other publications, to the effect that big companies will not disclose their results where geophysical methods have been applied.

It cannot be denied that frequently important features, such as locations, extent and value of their property, are not disclosed for commercial reasons, but beyond this the work done as regards geophysical investigations are willingly given to the cause of science, and if this is not forthcoming, then usually it means that the value of the work done in terms of geophysical significance cannot be definitely fixed.

As a preliminary to the study of geophysics Dr. Ambronn's book is well worth buying, and although other publications such as "Lehrbuch der Geophysik," by Dr. B. Gutenberg, will no doubt shortly be translated and published in England, the subject-matter is more detailed in its treatment and less readable in consequence to the lay mind or students.

W. R. MACDONALD.

BOOKS RECEIVED.

THE YORKSHIRE, NOTTINGHAMSHIRE AND DERBYSHIRE COALFIELD: SOUTH YORKSHIRE AREA, THE PARKGATE SEAM. Dept. of Scientific and Industrial Research. London: H.M. Stationery Office, 1929, pp. iv., 62, with 3 plates and 1 diagram. 3s. net.

This report, on the Parkgate Seam of the South Yorkshire area of the Yorkshire, Nottinghamshire and Derbyshire Coalfield, is the thirteenth of the series on the Physical and Chemical Survey of the National Coal Resources. The report gives the results of a comprehensive and detailed examination, from floor to roof, of sixteen complete sections of the seam taken at different points well distributed over the area. Each section was divided into sub-sections, and samples representing the average composition of each sub-section and of the whole seam section were prepared and analysed. Proximate and ultimate analyses, determinations of the calorific values and of the melting points of the ash, and laboratory carbonisation assays in the Gray-King apparatus were carried out upon each sample. In addition, samples of the four banded constituents (vitrain, clarain, durain and fusain) were picked by hand from each section and submitted to proximate and ultimate analyses. Appendices deal with general considerations of the use of Parkgate coal for various purposes, and the report includes a map of the South Yorkshire area, diagrams of sections of the seam and photographs of typical cokes from the Gray-King assay.